

Bioinspired Bare Bones Mayfly Algorithm for Large-Scale Spherical Minimum Spanning Tree

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Mayfly algorithm (MA) is a bioinspired algorithm based on population proposed in recent years and has been applied to many engineering problems successfully. However, it has too many parameters, which makes it difficult to set and adjust a set of appropriate parameters for different problems. In order to avoid adjusting parameters, a bioinspired bare bones mayfly algorithm (BBMA) is proposed. The BBMA adopts Gaussian distribution and Lévy flight, which improves the convergence speed and accuracy of the algorithm and makes better exploration and exploitation of the search region. The minimum spanning tree (MST) problem is a classic combinatorial optimization problem. This study provides a mathematical model for solving a variant of the MST problem, in which all points and solutions are on a sphere. Finally, the BBMA is used to solve the large-scale spherical MST problems. By comparing and analyzing the results of BBMA and other swarm intelligence algorithms in sixteen scales, the experimental results illustrate that the proposed algorithm is superior to other algorithms for the MST problems on a sphere.

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Zhang T, Zhou Y, Zhou G, Deng W and Luo Q (2022) Bioinspired Bare Bones Mayfly Algorithm for Large-Scale Spherical Minimum Spanning Tree. Front. Bioeng. Biotechnol. 10:830037. doi: 10.3389/fbioe.2022.830037 Keywords: mayfly algorithm, bare bones mayfly algorithm, large-scale spherical MST, Prüfer code, bioinspired algorithm

INTRODUCTION

Tree is a connected graph with simple structure which contains no loops and widely applied in graph theory (Diestel, 2000). The minimum spanning tree (MST) problem is a practical, wellknown, and widely studied problem in the field of combinatorial optimization (Graham and Hell, 1985). This problem has a long history, which was first put forward by Borüvka in 1926. Many engineering problems are solved based on MST (Bo Jiang, 2009), such as communications network design (Hsinghua et al., 2001), the construction of urban roads, the shortest path (Beardwood et al., 1959), distribution network planning, and pavement crack detection. There are some classical algorithms for solving MST, such as the Prim algorithm (Bo Jiang, 2009) and Kruskal algorithm (Joseph, 1956). They all belong to greedy algorithms, and generally, only one minimum spanning tree can be obtained. However, in practical application, it is usually necessary to find a group of minimum or subminimum spanning trees as the basis for scheme evaluation or selection. Therefore, finding an effective algorithm to solve MST problems is still a frontier topic. In recent years, a large number of bioinspired algorithms have been proposed, such as the marine predator algorithm (Faramarzi et al., 2020), chimp optimization algorithm (Khishe and Mosavi, 2020), arithmetic optimization algorithm (Abualigah et al., 2021), bald eagle search algorithm (Alsattar et al., 2020), Harris hawks optimization algorithm (Heidari et al., 2019), squirrel search

algorithm (Jain et al., 2018), pathfinder algorithm (Yapici and Cetinkaya, 2019), equilibrium optimizer (Faramarzi et al., 2019). The swarm intelligence algorithm has been widely used in various optimization problems and achieved good results, for example, path planning problems solved by the central force optimization algorithm (Chen et al., 2016), teaching-learning-based optimization algorithm (Majumder et al., 2021), water wave optimization algorithm (Yan et al., 2021), chicken swarm optimization algorithm (Liang et al., 2020), etc. Location problems are solved by the genetic algorithm (Li et al., 2021), particle swarm optimization (Yue et al., 2019), flower pollination algorithm (Singh and Mittal, 2021), etc. Also, the design of a reconfigurable antenna array is solved by the differential evolution algorithm (Li and Yin, 2011a), biogeography-based optimization (Li and Yin, 2011b), etc. In fact, the meta-heuristic algorithm can generate a set of minimum or subminimum spanning trees rather than one minimum spanning tree. The genetic algorithm (Zhou et al., 1996), artificial bee colony algorithm (Singh, 2009), ant colony optimization (Neumann and Witt, 2007), tabu search algorithm (Katagiri et al., 2012), and simulated annealing algorithm have been used for solving the MST problem.

For the MST problem, we usually calculate it in twodimensional space, but it is of practical significance to study MST in three-dimensional space. For example, sockets are connected with wires in cuboid rooms, and roads on hills and mountains are planned. Also, as we all know, the surface of the Earth where we live is very close to a sphere. In many research fields, atoms, molecules, and proteins are represented as spheres, and foods in life, such as eggs, seeds, onions, and pumpkins, are close to spheres. Some buildings, glass, and plastics are made into spheres. Similar to the traveling salesman problem (TSP), it is also an NP-hard problem. Now scholars have applied the cuckoo search algorithm (Ouyang et al., 2013), glowworm swarm optimization (Chen et al., 2017), and flower pollination algorithm (Zhou et al., 2019) to solve the spherical TSP. Thus, it is of essence crucial to study the MST on a three-dimensional sphere. Bi and Zhou have applied the improved artificial electric field algorithm to the spherical MST problem (Bi et al., 2021). In this article, we will further study the cases of more nodes on the sphere.

The mayfly algorithm (MA) proposed by Konstantinos Zervoudakis and Stelios Tsafarakis (2020) is a populationbased intelligent optimization bioinspired algorithm inspired by the flight and mating behavior of adult mayflies. Due to its high calculation accuracy and simple structure, researchers employed it to address problems of numerous disciplines. Guo and Kittisak Jermsittiparsert used improved MA to optimize the component size of high-temperature PEMFCpowered CCHP (Guo et al., 2021). Liu and Jiang proposed a multiobjective MA for a short-term wind speed forecasting system based on optimal sub-model selection (Liu et al., 2021a). Trinav Bhattacharyya and Bitanu Chatterjee combined MA with harmony search algorithm to solve the feature selection problem (Bhattacharyya et al., 2020). Liu and Chai used energy spectrum statistics and improved MA for bearing fault diagnosis (Liu et al., 2021b). Chen and Song

proposed the balanced MA to optimize the configuration of electric vehicle charging stations on the distribution system (Chen et al., 2021). MohamedAbd and ElazizaS. Senthilraja used MA to predict the performance of a solar photovoltaic collector and electrolytic hydrogen production system (AbdElaziz et al., 2021). To obtain a group of more perfect minimum spanning trees or subminimum spanning trees on a sphere in finite time, a bare bones mayfly algorithm (BBMA) is proposed to solve spherical MST problems. By simplifying the algorithm parameters and using the statistical update method, the fast convergence and solution accuracy of the proposed algorithm are better than before, and it shows superior ability in solving large-scale problems.

The rest of this article is organized as follows: *Related Work* describes the related work and basic mayfly algorithm. *The Proposed BBMA for Large-Scale Spherical MST* introduces the proposed bare bones mayfly algorithm for spherical MST. Comparison and analysis of results evaluated by BBMA and other algorithms are given in *Experimental Results and Discussion*. This article is concluded in *Conclusion and Future Work*.

RELATED WORK

Spherical Minimum Spanning Tree Mathematical Model

A semicircle takes its diameter as its axis of rotation, and the surface formed by rotation is called a sphere. The radius of the semicircle is the radius of the sphere. In this study, the coordinate origin (**Figures 1A,B**) is set as the center of the sphere. The equation of a sphere with radius r is

$$x^2 + y^2 + z^2 = r^2, (1)$$

where (x, y, z) is the coordinate of each point on the sphere.

Representation of Points on a Sphere

The coordinate position on the sphere can be expressed by the following formula (Hearn and Pauline Baker, 2004):

$$p(u, v) = (x(u, v), y(u, v), z(u, v)).$$
(2)

Each coordinate is represented by a function of the surface parameters u and v. Usually, we normalize the three coordinate functions and make u and v in the range of 0–1. **Eqs. 3–5** show a sphere with radius r, and the center is at the coordinate origin (Eldem and Ülker, 2017).

$$x(u,v) = r\cos(2\pi u)\sin(\pi v), \qquad (3)$$

$$y(u,v) = r\sin(2\pi u)\sin(\pi v), \qquad (4)$$

$$z(u,v) = r\cos(\pi v), \tag{5}$$

where parameters u and v determine a position by representing lines of constant longitude and lines of constant latitude, respectively. To simplify calculations, a sphere with r = 1 is used in this study. When the parameters u and v take different values, the coordinate position on the sphere is as shown in **Figure 1C** (Uğur et al., 2009).



Geodesics Between Point Pairs on a Unit Sphere

The circle of a sphere cut by the plane passing through the center of the sphere is called a great circle (Wikipedia, 2012). On the sphere, the length of the shortest connecting line between two points is the length of an inferior arc between the two points of the great circle passing through the two points. We call this arc length the geodesic (Lomnitz, 1995).

The geodesic between two points $p_i(x_i, y_i, z_i)$ and $p_j(x_j, y_j, z_j)$ on a sphere is shown in **Figure 1D**. These two points can be represented by two vectors $\vec{v}_i = (x_i, y_i, z_i)$ and $\vec{v}_j = (x_j, y_j, z_j)$. The scalar product of the two vectors is

$$\vec{v}_i \bullet \vec{v}_j = \left| \vec{v}_i \right| \left| \vec{v}_j \right| \cos \theta, \tag{6}$$

where θ is the angle between two vectors. The scalar product is calculated as

$$\vec{v}_i \bullet \vec{v}_j = x_i x_j + y_i y_j + z_i z_j. \tag{7}$$

Also, the shortest distance formula is

$$d_{p_i,p_j} = r\theta. \tag{8}$$

From Eqs 6-8, we get

$$\hat{d}_{p_i,p_j} = r \arccos\left(\frac{x_i x_j + y_i y_j + z_i z_j}{r^2}\right).$$
(9)

The distance from point p_i to point p_j is the same as the distance from p_j to p_i . If there are *n* points on the sphere, an

 $n \times n$ symmetric distance matrix D will be obtained by calculating the distance between each two points. The matrix D is as follows:

$$D = \begin{bmatrix} \hat{d}_{11} & \hat{d}_{12} & \cdots & \hat{d}_{1n} \\ \hat{d}_{21} & \hat{d}_{21} & \cdots & \hat{d}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \hat{d}_{n1} & \hat{d}_{n2} & \cdots & \hat{d}_{nn} \end{bmatrix} = \begin{bmatrix} \infty & \hat{d}_{12} & \cdots & \hat{d}_{1n} \\ \hat{d}_{21} & \infty & \cdots & \hat{d}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \hat{d}_{n1} & \hat{d}_{n2} & \cdots & \infty \end{bmatrix}, \quad (10)$$

where $d_{i,j}$ represents the length of the geodesic between point p_i and point p_j . In particular, $\hat{d}_{i,i} = \infty$ means that point p_i cannot reach itself.

Spherical Minimum Spanning Tree Mathematical Model

For the two-dimensional MST problem, G = (V, E) represents an undirected graph, where $V = \{v_1, v_2, \dots, v_n\}$ is a finite set of nodes and $E = \{e_{ij} | v_i, v_j \in V\}$ is a finite set of edges. Each has its corresponding weight w_{ij} . x_{ij} ($i, j = 1, 2, \dots, n$) is set as 0 or 1. If $x_{ij} = 1$, e_{ij} is selected; if $x_{ij} = 0$, e_{ij} is not selected. The variable |S| is the number of nodes of the graph contained in the set *S*. The mathematical model of the minimum spanning tree is as follows:

$$\min f(x) = \sum_{i=1}^{n-1} \sum_{j=1+1}^{n} w_{ij} x_{ij},$$
(11)

$$s.t.\sum_{i=1}^{n-1}\sum_{j=1+1}^{n}x_{ij}=n-1,$$
(12)

$$\sum_{v_i \in S} \sum_{v_j \in S, i < j} x_{ij} \le |S| - 1, \forall S \in V, |S| \ge 2,$$
(13)

$$x_{ij} \in \{0, 1\}$$
 $i, j = 1, 2, \cdots, n,$ (14)

where the constraint condition **Eq. 12** ensures that the last generated graph is a spanning tree. Also, constraint condition **Eq. 13** ensures that it is not a circle in the process of solving the minimum spanning tree problem.

As for a 3*D* spherical minimum spanning tree problem, a finite set of nodes $P = \{p_1, p_2, \dots, p_n\}$ are on a sphere. Each node is represented by $p_i = (x_i, y_i, z_i)$. $A = \{a_{ij} | p_i, p_j \in V\}$ is a finite set of geodesics. Each geodesic has its corresponding weight \hat{d}_{ij} which is calculated by **Eq. 9**. An $n \times n$ symmetric distance matrix *D* can be constructed as shown in **Eq. 10**. $x_{ij} (i, j = 1, 2, \dots, n)$ is set as 0 or 1. If $x_{ij} = 1$, a_{ij} is selected; if $x_{ij} = 0$, a_{ij} is not selected. The variable |S| is the number of nodes on a sphere. The mathematical model of the spherical MST is as follows:

$$\min f(x) = \sum_{i=1}^{n-1} \sum_{j=1+1}^{n} \hat{d}_{ij} x_{ij}.$$
(15)

Similarly, constraint condition Eqs 12-14 are applied to Eq. 15.

Mayfly Algorithm

Mayfly algorithm is a new swarm intelligence bioinspired algorithm proposed in 2020. Its inspiration comes from the flying and mating behavior of male and female mayflies in nature. The algorithm can be considered as a modification of particle swarm optimization (PSO) (Kennedy and Eberhart, 1995), genetic algorithm (GA) (Goldberg, 1989), and firefly algorithm (FA) (Yang, 2009). At present, researchers have applied MA to many engineering problems.

Mayflies are insects that live in water when they are young. The feeding ability will be lost, and they only mate and reproduce when they grow up. In order to attract females, most adult male mayflies gather a few meters above the water to perform a nuptial dance. Then, female mayflies fly into these swarms to mate with male mayflies. After mating, the females lay their eggs on the water, and the mated mayflies will die.

In MA, the two idealized rules should be followed. First, after mayflies are born, they are regarded as adults. Second, the mated mayflies which have stronger ability to adapt to the environment can continue to survive. The algorithm works as follows. First, male and female populations are randomly generated. Each mayfly in the search space is regarded as a candidate solution represented by a *d*-dimensional vector $X = (x_1, x_2, \dots, x_d)$ for male and Y = (y_1, y_2, \dots, y_d) for female. Its performance is evaluated according to the objective function $f(\cdot)$ shown in **Eq. 15**. The velocity of each mayfly is expressed by $V = (v_1, v_2, \dots, v_d)$. The flying direction of each male mayfly is guided by its best location in history and the global optimal position in the population. Meanwhile, the female mayflies fly to the corresponding male mayflies. The main steps of mayfly algorithm are described as follows.

Movement of Male Mayflies

The gathering of male mayflies in a swarm is always a few meters above water for performing the nuptial dance. The position of a male mayfly is updated as follows:

$$x_i^{t+1} = x_i^t + v_i^{t+1}, (16)$$

where x_i^t is the position of mayfly *i* at time *t* and x_i^{t+1} is the position at time t + 1 and v_i^{t+1} is the velocity of mayfly *i* at time t + 1. The velocity is adjusted by its own velocity and individual and social experiences at time *t*. However, the best male mayfly in the population is not affected by other mayflies, which helps the algorithm escape the local optimal. The velocity of a male mayfly *i* is calculated as

$$v_{ij}^{t+1} = \begin{cases} v_{ij}^t + \alpha_1 \cdot e^{-\beta r_p^2} (pbest_{ij} - x_{ij}^t) + \alpha_2 \cdot e^{-\beta r_g^2} (gbest_j - x_{ij}^t), \\ f(x_i^t) > f(gbest) v_{ij}^t + d \cdot r, f(x_i^t) = f(gbest), \end{cases}$$

$$(17)$$

$$r_p = \sqrt{\sum_{j=1}^{n} (x_{ij} - pbest_{ij})^2},$$
 (18)

$$r_g = \sqrt{\sum_{j=1}^n \left(x_{ij} - gbest_j\right)^2},\tag{19}$$

where v_{ij}^t represents the velocity of male mayfly *i* at time *t* in dimension $j (j = 1, 2, \dots, n)$, x_{ij}^t represents the position of dimension *j* of mayfly *i* at time *t*, α_1 and α_2 represent positive attraction constants used to scale the contribution of the cognitive and social component, respectively, and β is a fixed visibility coefficient used to limit a mayfly's visibility to others. Furthermore, the best individual historical position of mayfly *i* is represented by *pbest_i* and *gbest* is the global best position at time step *t*, while r_p is the Cartesian distance between x_i and *gbest_i* and r_g is the Cartesian distance between x_i and *gbest_i*. These distances are calculated according to **Eq. 18, 19**. Finally, *d* is the nuptial dance coefficient and $r \in [-1, 1]$ is a random value.

Movement of Female Mayflies

The female mayflies move toward the males for breeding. The position of a female mayfly is updated as follows:

$$y_i^{t+1} = y_i^t + v_i^{t+1},$$
 (20)

where y_i^t is the position of female mayfly *i* at time *t* and y_i^{t+1} is the position at time step t + 1 and v_i^{t+1} represents the velocity of female mayfly *i* at time t + 1. Its velocity is affected by its own velocity and the corresponding male mayfly's position. It means that according to their fitness function, the best female should be attracted by the best male, the second best female by the second best male, and so on. However, the female mayfly which is better than the corresponding male mayfly is not affected by a male, it flies randomly. Consequently, considering minimization problems, their velocities are calculated as

$$v_{ij}^{t+1} = \begin{cases} v_{ij}^{t} + \alpha_2 \cdot e^{-\beta r_{mf}^2} \left(x_{ij}^{t} - y_{ij}^{t} \right), f\left(y_i^{t} \right) > f\left(x_i^{t} \right) \\ v_{ij}^{t} + fl \cdot r, f\left(y_i^{t} \right) \le f\left(x_i^{t} \right) \end{cases}$$
(21)

$$r_{mf} = \sqrt{\sum_{j=1}^{n} (x_{ij} - y_{ij})^2},$$
 (22)

where v_{ij}^t is a velocity of female mayfly *i* at time *t*, y_{ij}^t is the position in dimension *j* at time *t*, α_2 is the positive attraction constant, and β represents an unchanged visibility coefficient. r_{mf} represents the

distance between x_i and y_i calculated according to **Eq. 22**. Finally, fl is the random fly coefficient, and $r \in [-1, 1]$ is a random value.

Mating of Mayflies

The mating rules are the same as the way females are attracted by males. The best female breeds with the best male, the second best female with the second best male, and so on. The positions of two offspring are generated by the arithmetic weighted sum of the positions of parents as follows:

$$offspring1 = L \cdot male + (1 - L) \cdot female$$

$$offspring2 = L \cdot female + (1 - L) \cdot male'$$
(23)

where *male* is the male mayfly's position, *female* is the female mayfly's position, and $L \in [-1, 1]$ is a random value. Offspring's initial velocities are set to be zero, which helps the convergence of the algorithm.

After mating, the offspring are mixed with male and female parents. Then, the fitness values are sorted. The mayflies with low adaptability will die, and those with high adaptability will live for the next iteration. Algorithm 1 shows the pseudocode of MA.

Algorithm 1. Mayfly algorithm.

Initialize male mayfly population X and velocity V
Initialize female mayfly population Y and velocity V
Evaluate solutions
Find global best gbest
While ($t \le MaxGeneration$)
Update velocities and solutions of males via Eq.13 and Eq.14
Update velocities and solutions of females via Eq.17 and Eq.18
Calculate fitness values
Rank males and females respectively
Male mayflies mate with female mayflies via Eq.20
Calculate fitness values of offspring
The offspring are randomly distributed equally to the male and female groups
Rank males and females respectively and individuals with poor adaptability will die
Update <i>pbest</i> and <i>gbest</i>
end while
Output the best solution

THE PROPOSED BBMA FOR LARGE-SCALE SPHERICAL MST

MST Based on Prüfer Coding

A coding method for marking rootless trees is called Prüfer coding. The initial population generated by this coding method will not produce infeasible solutions after being improved. Prüfer coding is needed to solve the spherical MST. Its idea comes from Cayley's theorem, which means that there are n^{n-2} different minimum spanning trees for a complete graph with n nodes (Crabb, 2006). It shows that the arrangement of n-2 numbers can uniquely represent a tree, and these numbers are integers between 1 and n. Such an arrangement that can represent a tree is the Prüfer sequence. The process of converting a tree into a Prüfer sequence is as follows:

Step 1: node *i* is the leaf node with the smallest value on the tree *T*Step 2: the node *j* uniquely connected to *i* is taken as the first coding number, and the coding order is from left to right



Step 3: node *i* and the edge from *i* to *j* are deleted, and a n-1 node tree is obtained

Step 4: this is repeated until only one edge is left

Through the abovementioned steps, we can get a Prüfer sequence of tree *T* which is n - 2 permutations of the numbers between 1 and *n*.

Code Design

We assume that there are *n* points on a sphere, and these points are represented by different integers between 1 and *n*. The dimension of the position of each individual is n - 2, and the value in each dimension is a real number between 1 and *n*.

Suppose an individual is represented by

$$X_1: (1.75, 7.13, 3.84, 2.12, 4.26, 5.06).$$
(24)

The Prüfer sequence obtained by rounding X_1 is as follows: $X_1 \rightarrow X_2$: (2, 7, 4, 2, 4, 5). (25)

According to X_2 , the spanning tree shown in **Figure 2** is obtained. The pseudo code of decoding the Prüfer sequence into a tree is shown in Algorithm 2.

Algorithm 2. Decoding the Prüfer sequence into a tree.

Initialize an empty tree T and get a Prüfer sequence P
Find vertices that are not in set P and put them in set Q
While (there are elements in the set P)
Arrange the elements in set Q in ascending order
Let i be the leftmost element in set Q
Let j be the leftmost element in set P
Connect node i to node j and add them to tree T
Remove node i from set Q
Remove node <i>j</i> from set <i>P</i>
If (node j is not in set P)
Put node j into set Q
End if
End while
Add the two nodes left in the set Q to the tree T and connect the two nodes
Output the tree T

	Algorithms	Best	Worst	Mean	Std	Rank
25	BBMA	13.6447	18.7544	15.8919	1.0202	1
	MA	15.8860	20.9488	17.8316	1.2093	3
	AEFA, Bi et al. (2021)	19.3017	28.3577	23.9500	1.9339	11
	PSO, Bi et al. (2021)	18.6661	25.1622	22.1693	1.6687	8
	ICA, Bi et al. (2021)	18.1877	25.3421	21.8561	1.7114	6
	GA, Bi et al. (2021)	22.7281	28.0316	26.1953	1.2759	12
	GOA, Bi et al. (2021)	19.8519	26.1873	23.0678	1.6544	10
	GWO, Bi et al. (2021)	16.9782	27.0574	22.5108	2.3995	9
	SOA, Bi et al. (2021)	18.8431	24.4946	21.9361	1.3878	7
	SMA, Bi et al. (2021)	15.0231	19.8995	17.6528	1.2658	2
	DE	16.9290	21.1576	18.8842	1.0401	4
	AMO	16.5514	20.6010	19.0003	0.8266	5
50	BBMA	28.4447	37.2789	34.8170	1.7546	1
	MA	34.3380	58.6173	42.2226	4.4855	2
	AEFA, Bi et al. (2021)	50.2250	59.3597	55.1098	2.4704	8
	PSO, Bi et al. (2021)	44.8040	57.2689	51.5060	3.0896	5
	ICA, Bi et al. (2021)	45.7038	58.0749	52.4320	2.7355	7
	GA, Bi et al. (2021)	55.3518	64.8996	61.6177	2.3682	12
	GOA, Bi et al. (2021)	50.5135	58.4612	55.3181	2.0431	9
	GWO, Bi et al. (2021)	51.8792	59.9504	57.8262	1.5102	11
	SOA, Bi et al. (2021)	53.8901	58.4334	56.5395	1.2611	10
	SMA, Bi et al. (2021)	41.6473	54.8003	47.6913	3.0873	3
	DE	48.4642	54.5281	51.7636	1.6024	6
	AMO	45.0359	51.8286	48.9038	1.4479	4
75	BBMA	48.6839	59.3288	54.7791	3.5118	1
	MA	59.7131	93.1400	76.1626	11.7156	2
	AEFA, Bi et al. (2021)	78.5702	93.0950	87.1792	3.7266	8
	PSO, Bi et al. (2021)	76.2217	83.4455	83.4455	3.0984	5
	ICA, Bi et al. (2021)	74.9482	95.2576	85.2616	4.4489	6
	GA, Bi et al. (2021)	92.5715	104.4691	98.6174	2.8997	12
	GOA, Bi et al. (2021)	82.9354	95.4337	87.8587	3.1684	9
	GWO, Bi et al. (2021)	89.7958	96.8943	93.2198	1.9073	10
	SOA, Bi et al. (2021)	88.1649	99.3988	95.7273	2.6763	11
	SMA, Bi et al. (2021)	73.2677	88.9004	82.6417	4.0689	4
	DE	81.4543	88.4035	85.4406	1.5659	7
	AMO	72.7859	83.5528	79.9430	2.6396	3
100	BBMA	69.2455	82.8067	76.9687	3.358	1
	MA	93.0942	132.0213	117.2067	13.3847	5
	AEFA, Bi et al. (2021)	108.6233	132.4447	121.9061	5.5434	8
	PSO, Bi et al. (2021)	105.3880	122.9785	114.8626	4.8750	2
	ICA, Bi et al. (2021)	113.1387	130.8257	120.4606	4.4412	6
	GA, Bi et al. (2021)	122.6827	141.3354	136.5707	3.5123	12
	GOA, Bi et al. (2021)	115.5154	131.2544	124.3536	4.3611	9
	GWO, Bi et al. (2021)	115.5757	132.9414	128.5117	3.6147	10
	SOA, Bi et al. (2021)	124.2706	132.8262	129.5164	2.4841	11
	SMA. Bi et al. (2021)	102.8094	127,4766	116.7717	4.8956	4
	DE	115.9142	125.0204	120.9535	2.0062	7

The optimal values are shown in bold.

The **BBMA** Algorithm

The basic MA has the problem of many initial parameters which have a great impact on the results. Besides, the accuracy of MA is not high enough due to lack of exploitation ability. Bare bones mayfly algorithm avoids the influence of parameters by cancelling the velocity (Ning and Wang, 2020; Song et al., 2020), and individual position is directly obtained by random sampling obeying Gaussian distribution like bare bones PSO (Kennedy, 2003). In order to enhance the exploitation ability and help the algorithm escape from the local optimal solution, BBMA uses Lévy flight to perform the nuptial dance of the optimal male and the random flight of the excellent female (Nezamivand et al., 2018). In addition, individuals crossing the border are pulled back into the search space instead of the method of placing cross-border individuals on the boundary so that it reduces the waste of search space (Wang et al., 2016). The main steps of BBMA are described as follows.

Movement of Male Mayflies

Male mayflies can be renewed in two ways as before. First, for individuals who are not the best, the Gaussian distribution based on the global optimal position and individual historical optimal position is used to calculate the position. In order to keep a balance between the diversity and convergence of algorithm, a disturbance which changes adaptively based on the diversity of



the population and the convergence degree of the current individual is added (Zhang et al., 2014). The new update strategy is described as follows:

 x_i^t

$$^{+1} = N(\mu, \sigma^2),$$
 (26)

$$\mu = \frac{\left(gbest_j + pbest_{ij}\right)}{2}, \sigma = \left|gbest_j - pbest_{ij}\right| + \delta, \qquad (27)$$

$$\delta = rand \cdot |x_{k1,j} - x_{k2,j}| \cdot e^{f(gbest) - f(x_i)}, \qquad (28)$$

where $N(\mu, \sigma^2)$ is the Gaussian distribution with mean μ and standard deviation σ , *gbest* represents the global optimal individual, *pbest_i* is the historical optimal solution of individual *i*, *rand* $\in [0, 1]$ is a random value, and x_{k1} and x_{k2} are two solutions selected from other male mayflies at random.

We know that the population is scattered in the early stage of evolution, so σ is large, and the Gaussian distribution is scattered, which is conducive for global search. In the later stage of evolution, the population is relatively concentrated, and individuals search carefully around μ . However, if the *pbest* of a individual happens to be close or equal to *gbest* in the evolution process, this individual will stop updating because the variance of Gaussian distribution

becomes 0. Also, if most individuals among the swarm stop updating prematurely, the algorithm will converge to a false global optimum with high probability. Thus, assigning a disturbance on the variance of Gaussian distribution is a good way. As shown in **Eq. 28**, on the assumption that $|x_{k1,j} - x_{k2,j}|$ remains constant, the smaller the differential fitness value between *gbest* and x_i , the higher the disturbance δ . When the individual has the same fitness as *gbest*, this individual will be affected by a disturbance with the maximal magnitude. In this case, this disturbance may prevent the algorithm from trapping into a local optimal solution. Furthermore, with the iteration of the algorithm, individuals get denser and denser. The smaller the value of $|x_{k1,j} - x_{k2,j}|$, the smaller the δ and σ , which ensures the convergence of the algorithm.

As for the second individual update method, if the individual is the global optimal solution, Lévy flight is adopted. The small step size of Lévy flight improves the exploitation ability of the algorithm, and the less long step increases the ability of avoiding getting stuck in a local optimal value (Dinkar and Deep, 2018; Ren et al., 2021). By using Lévy flight, the overall performance of BBMA in solving large-scale problems has been greatly enhanced. In fact, Lévy flight is a random walk, which follows the Lévy distribution of the following formulas:

$$Levy(s) \sim s^{-1-\beta}, 0 \le \beta \le 2,$$
(29)

$$s = \frac{A}{|B|^{1/\beta}}, A \sim N(0, \sigma_A^2), B \sim N(0, \sigma_B^2),$$
(30)

$$\sigma_A = \left(\frac{\Gamma\left(1+\beta\right) \cdot \sin\left(\frac{\pi\beta}{2}\right)}{\Gamma\left(1+\frac{\beta}{2}\right) \cdot \beta \cdot 2^{\frac{\beta-1}{2}}}\right)^{1/\beta}, \sigma_B = 1,$$
(31)

$$\Gamma(1+\beta) = \int_0^\infty t^\beta e^{-t} dt, \qquad (32)$$

where *s* represents the step size and β is an index by which the peak sharpness of the Lévy distribution can be adjusted. In this work, we set $\beta = 1.5$. *A* and *B* follow the Gaussian distribution, and Γ stands for the gamma function which is obtained by **Eq. 32**. For the best individual, the update formula is as follows:

$$x_i^{t+1} = x_i^t + x_i^t \cdot Levy(\beta).$$
(33)

By using Lévy flight to search the solution space, the global exploration ability and local exploitation ability of the algorithm are better balanced.

Movement of Female Mayflies

Female mayflies can be renewed in two ways as before. Firstly, for individuals who are worse than their corresponding male mayflies, the Gaussian distribution based on the current female mayfly's position and its corresponding male mayfly's position is used to calculate the position. The new update strategy is described as follows:

$$y_i^{t+1} = N\left(\mu, \sigma^2\right),\tag{34}$$

$$\mu = \frac{\left(x_{ij} + y_{ij}\right)}{2}, \sigma = \sqrt{\left|x_{ij} - y_{ij}\right|},\tag{35}$$

where $N(\mu, \sigma^2)$ is the Gaussian distribution, y_{ij} is the position of the female mayfly, and x_{ij} is the position of its corresponding male mayfly. The root sign makes the Gaussian distribution relatively concentrated so that it ensures female mayflies approach male mayflies faster, which accelerates the convergence.

As for the second individual update method, if the female mayfly is better than its corresponding male mayfly, the excellent female mayfly, like the best male mayfly, should use the strategy of Lévy flight which will make the algorithm get rid of the local optimum (Barshandeh and Haghzadeh, 2020). For excellent female mayflies, the update formula is as follows:

$$y_i^{t+1} = y_i^t + y_i^t \cdot Levy(\beta).$$
(36)

Both Gaussian distribution and Lévy distribution are statistical random distribution. The distribution of the former is regular, and the distribution of the latter is irregular. Their cooperation can prevent the lack of diversity of the algorithm and improve the convergence speed.

Mating of Mayflies

The mating process is the same as the basic MA as shown in **Eq. 23**. After mating, the offspring are mixed with parents. Then, the mayflies with low adaptability will die, and those with high adaptability will live for the next iteration.

Handling Cross-Border Mayflies

In the early stage of population evolution, the distance between the historical optimal position and the global optimal position of different individuals is far away, and the standard deviation σ of Gaussian distribution used for updating positions is relatively large, resulting in a greater opportunity for the new position to cross the boundary of the search space. In basic MA, the position of the cross-border individual is directly placed on the boundary, which will result in a waste of resources. In this study, according to the degree of individuals crossing the boundary, with the expectation μ of Gaussian distribution as the center, the crossborder individual *x* is pulled back to the search space to obtain *x'*, and the cross-border individual is treated according to **the** following equation:

$$x' = \mu + \frac{(x_{border} - \mu)^2}{x - \mu},$$
 (37)

where x_{border} is the boundary, we assume x_{max} is the upper bound and x_{min} is the lower bound, if $x > x_{max}$, $x_{border} = x_{max}$, and if $x < x_{min}$, $x_{border} = x_{min}$. According to Eq. 37, when x crosses the upper bound, it is pulled back to the interval (μ, x_{max}) . The less the x crosses x_{max} , the closer it is pulled back to x_{max} ; the more the x crosses x_{max} , the closer it is pulled back to the center μ . When x crosses the lower bound, it is pulled back to the interval (x_{min}, μ) . Similarly, the degree to which individuals are pulled back into the search space is proportional to the degree of individuals crossing the boundary.

The concrete implementation steps of the bare bones mayfly algorithm for spherical MST are as follows.

Algorithm 3. The BBMA for spherical MST.

Initialize male mayfly population X
Initialize female mayfly population Y
Each mayfly represents one spanning tree
Evaluate solutions
Find global best gbest
While ($t \le MaxGeneration$)
Update velocities and solutions of males via Eq.26 and Eq.33
Update velocities and solutions of females via Eq.34 and Eq.36
Calculate fitness values
Rank males and females respectively
Male mayflies mate with female mayflies via Eq.20
Calculate fitness values of offspring
The offspring are randomly distributed equally to the male and female groups
Rank males and females respectively and individuals with poor adaptability will die
Update <i>phest</i> and <i>ghest</i>
end while
Output the best solution

EXPERIMENTAL RESULTS AND DISCUSSION

A large number of cases with different number of points are used to test the ability of BBMA in solving MST problems. All experiments are carried out on a sphere with r = 1, and the number of nodes the sphere is n = 25, 50, 75, 100, 150, 200, 250, 300, 350, 400, 500, 600, 700, 800, 900, and 1,000, The data and



FIGURE 4 | The ANOVA test for low dimensions. (A) The ANOVA test for 25 points. (B) The ANOVA test for 50 points. (C) The ANOVA test for 75 points. (D) The ANOVA test for 100 points.

results of 400 nodes or less come from the literature (Bi et al., 2021) and the node data in higher dimensions are randomly generated. Due to the randomness of meta-heuristic algorithm, each case is run 30 times independently. The structure of this section is as follows: in *Experimental Setup*, the experimental setup is given; *Comparison of Algorithms in Low-Dimensional Cases* shows the comparison and analysis of experimental results between BBMA and other algorithms in the cases of low dimension; the comparison for medium-dimensional cases is shown in *Comparison of Algorithms for Medium-Dimensional Cases*; and the high-dimensional cases are shown in *Comparison of Algorithms for High-Dimensional Cases*.

Experimental Setup

All of the experiments are compiled in MATLAB R2019a. System specification: an Intel Core i3-6100 processor, 8 GB RAM is used. In this work, we set the population size of all algorithms to 30, and each algorithm iterates 300 generations. BBMA is compared with the mayfly algorithm (MA), artificial electric field algorithm (AEFA) (Anita and Yadav, 2019), GA (Holland, 1992), PSO (Kennedy and Eberhart, 1995), imperialist competitive algorithm (ICA) (Atashpaz-Gargari and Lucas, 2008), seagull optimization algorithm (SOA) (Dhiman and Kumar, 2019), grasshopper optimization algorithm

(GOA) (Storn and Price, 1997), grey wolf optimization (GWO) (Li et al., 2014), slime moth algorithm (SMA) (Saremi et al., 2017), differential evolution (DE) (Mirjalili et al., 2014), and animal migration optimization (AMO) (Li et al., 2020) in the best value, worst value, mean value, and standard deviation. In addition, in order to clearly prove the effectiveness of BBMA, the convergence curves, ANOVA test, fitness values for 30 runs, running time, and Wilcoxon rank-sum non-parametric statistical test (Derrac et al., 2011; Gibbons and Chakraborti, 2011) are also compared. Also, the minimum spanning tree is showed in spheres. The control parameters of each algorithm are as follows (Bi et al., 2021):

- BBMA: no parameters
- MA: positive attraction constants $\alpha_1 = 1$, $\alpha_2 = 1.5$, visibility coefficient $\beta = 2$, nuptial dance coefficient d = 0.1, and random walk coefficient fl = 0.1 (Zervoudakis and Tsafarakis, 2020)
- AEFA: Coulomb's constant $K_0 = 500$ (Anita and Yadav, 2019)
- PSO: inertia weight g = 0.2, self-cognitive coefficient C1 = 0.7, and social learning coefficient C2 = 1 (Kennedy and Eberhart, 1995)



FIGURE 5 | Fitness values for 10w dimensions. (A) Fitness values for 30 runs for 25 points. (B) Fitness values for 30 runs for 50 points. (C) Fitness values for 30 runs for 75 points. (D) Fitness values for 30 runs for 100 points.

TABLE	ABLE 2 Wilcoxon rank-sum test results in low dimensions.												
Points	MA	AEFA	PSO	ICA	GA	GOA	GWO	SOA	SMA	DE	AMO		
25	1.0570E-04	1.7344E-06	1.9209E-06	1.7344E-06	1.7344E-06	1.7344E-06	2.1266E-06	1.7344E-06	1.4773E-04	5.7517e-06	1.7344E-06		
50	1.7344E-06	1.7344E-06	1.7344E-06	1.9209E-06	1.7344E-06								
75	1.7344E-06	1.7344E-06	1.7344E-06	1.7344E-06	1.7344E-06	1.7344E-06	1.7344E-06	1.7344E-06	1.7344E-06	1.7344E-06	1.7344E-06		
100	1.7344E-06	1.7344E-06	1.7344E-06	1.7344E-06	1.7344E-06	1.7344E-06	1.7344E-06	1.7344E-06	1.7344E-06	1.7344E-06	1.7344E-06		

- ICA: selection pressure is 1, assimilation coefficient is 2, revolution probability is 0.5, revolution rate is 0.1, and colony mean cost coefficient is 0.1 (Atashpaz-Gargari and Lucas, 2008)
- GA: crossover probability is 0.8, and mutation probability is 0.8 (Holland, 1992)
- GOA: intensity of attraction f = 0.5, attractive length scale l = 1.5, and the maximum and minimum values of the decline coefficient are $c_{\text{max}} = 1$ and $c_{\text{min}} = 0.00004$ (Dhiman and Kumar, 2019)
- GWO: convergence factor *a* decreases linearly from 2 to 0 (Storn and Price, 1997)

- SOA: *f_c* that controls migration behavior decreases linearly from 2 to 0 (Li et al., 2014)
- SMA: foraging success probability z = 0.03 (Saremi et al., 2017)
- DE: scaling factor *F* = 0.5, and crossover constant *CR* = 0.5 (Mirjalili et al., 2014)
- AMO: no parameters (Li et al., 2020)

Comparison of Algorithms in Low-Dimensional Cases

Cases with 25, 50, 75, and 100 points are used to compare the performance of algorithms mentioned above, and the results of 30

TABLE 3 | Experimental results for the twelve algorithms for 150, 200, 250, 300, 350, and 400 points.

150 BMA 102.704 122.805 121.805 6.0033 MFA Bit al. (2021) 177.1650 903.9658 182.839 5.26970 PSO, Bit al. (2021) 177.1650 192.9477 193.8707 5.6977 QA, Bit al. (2021) 170.8946 195.9464 195.846 5.6997 QA, Bit al. (2021) 181.2130 205.7132 193.777 5.0473 GOA, Bit al. (2021) 190.2580 210.1586 2.7155 5.045 SAA, Bit al. (2021) 190.3280 210.1381 191.779 2.0473 SAA, Bit al. (2021) 190.4786 194.83918 191.7898 2.08120 DE 180.4898 194.9318 191.7898 2.0822 ANO 172.0064 155.718 181.79984 2.0822 PE 180.4897 196.8385 17.96982 2.0824 AND 17.710 2.01737 2.0473 2.4667 SAA 194.4921 2.23149 2.77469 223.999 7.7842 CA	Points	Algorithms	Best	Worst	Mean	Std	Rank
MA 198.2039 203.8459 187.3844 15.6985 AFFA, Bi et al. (2021) 177.1469 196.25427 183.8670 5.7007 ICA, Bi et al. (2021) 205.0229 210.0766 27.3846 5.6397 ICA, Bi et al. (2021) 205.0229 210.0768 2.10.0769 </td <td>150</td> <td>BBMA</td> <td>108.7044</td> <td>128.5096</td> <td>121.2003</td> <td>6.0033</td> <td>1</td>	150	BBMA	108.7044	128.5096	121.2003	6.0033	1
APFA, Bit et. (2021) 177,1496 199,1925 199,19350 5.2370 ICA, Bit et. (2021) 170,8904 195,5246 187,3846 5.697 ICA, Bit et. (2021) 190,2094 190,5296 193,777 2.6473 GOA, Bit et. (2021) 191,2130 205,7152 193,7471 5.9165 SDA, Bit et. (2021) 196,1238 201,1148 205,7050 2.7155 SDA, Bit et. (2021) 196,1238 201,13471 153,4648 4.2731 DE 196,4358 191,4561 191,7288 2.082 AMO 195,0171 193,3280 281,414 203,4648 4.2731 DE 196,4553 196,4553 175,5552 6.4051 AMA 192,47737 273,2994 267,4996 7.6321 ICA, Bit et. (2021) 224,7973 273,2994 267,4996 7.6321 ICA, Bit et. (2021) 224,7974 273,2994 267,4996 7.6321 ICA, Bit et. (2021) 224,7974 273,2994 267,4996 7.6421 ICA, Bit		MA	159 5308	203 8459	187.3684	15 6695	5
PBOL Bit al. (2021) 171.8990 192.9427 193.9970 5.7997 ICA B. et al. (2021) 170.8206 195.2540 197.3746 6.5916 GA, D. et al. (2021) 198.12180 205.1918 201.6552 4.6914 GVA, B. et al. (2021) 198.12980 205.1918 201.7777 2.0473 SVA, B. et al. (2021) 198.42968 194.9518 197.8988 2.0213 SVA, B. et al. (2021) 198.42968 194.9518 193.8486 4.2731 DE 198.42968 194.9518 193.8486 2.02286 AMO 175.0964 195.5535 175.8552 6.4563 MA 220.322 284.2144 203.1465 7.7713 PSO, B. et al. (2021) 243.6783 243.4991 6.6541 ICA, E. et al. (2021) 243.7737 273.2264 254.6991 6.6541 ICA, E. et al. (2021) 243.771 275.255 205.2995 7.713 ISA, B. et al. (2021) 243.771 275.1255 205.2976 263.1981 2.199.11 3.31445 </td <td></td> <td>$\Delta FE \Delta$ Bi et al. (2021)</td> <td>177 1469</td> <td>195 8829</td> <td>186 8330</td> <td>5 2970</td> <td>4</td>		$\Delta FE \Delta$ Bi et al. (2021)	177 1469	195 8829	186 8330	5 2970	4
IAA Bet al. (2021) 170:2049 195:5346 197:3346 5.0597 GAA Bet al. (2021) 191:130 205.7132 193.777 2.0473 SDA, Bet al. (2021) 199:13280 201.148 205.7052 193.777 2.0473 SDA, Bet al. (2021) 199:13280 201.148 205.7050 2.7165 SDA, Bet al. (2021) 196:4058 194.9518 191.7888 2.0682 AMO 195:4078 196.5355 175.9552 6.4658 AMA 192.8147 273.2064 257.9553 7.454 PSO, Bit al. (2021) 241.8333 266.7025 254.6691 6.3041 ICA, Bit al. (2021) 241.8332 266.7026 257.9556 7.6342 GA, Bit al. (2021) 241.8332 266.7035 277.9552 2.4667 ICA, Bit al. (2021) 241.7373 273.2064 277.9552 2.4667 ICA, Bit al. (2021) 241.7374 205.3083 242.3761 3.3149 ICA, Bit al. (2021) 241.7373 273.2064 277.9552 2.4667		PSO Bi et al. (2021)	171.8660	102 5/27	183 8670	5 7697	
CAL Bir di J. (2021) 203.0229 200.798 1106852 4.8071 GAX, Bir di J. (2021) 198.1218 205.1307 20.7776 2.0773 GAX, Bir di J. (2021) 198.0390 210.1148 205.7776 2.0715 SNA, Bir di J. (2021) 194.0798 210.13637 193.0468 4.2731 DE 198.0468 194.51718 183.0468 4.2731 DE 198.0476 196.5552 6.4689 3.3511 AMO 175.0044 195.1718 183.0476 2.0228 AMA 223.146 277.466 255.0136 2.0228 CA, Bir di L. (2021) 246.737 277.2663 224.4061 5.8540 GOA, Bir di L. (2021) 246.737 277.0680 273.0821 2.7613 SDA, Bir di L. (2021) 245.7519 275.1555 260.9996 7.8422 GA, Bir di L. (2021) 247.719 275.1255 260.9966 8.6136 SDA, Bir di L. (2021) 245.2719 275.1255 260.9966 8.6136 GA, Bir di L. (2021)		ICA Ri et al. (2021)	170.6246	105 5046	197 2946	5.6007	2
Cook, Bir et al., (2021) 203, Cock 218, Core 218, Core 100, Core 59105 ONO, Bir et al., (2021) 106, 128, 202 210, 116 200, Core 24713 2473 SMA, Bir et al., (2021) 106, 2078 2110, 116 200, 207, 202 2110, 116 DE 106, 4078 211, 357 1183, 648, 42721 126, 116 200, 116 AMO 178, 9497 116, 1178 211, 357 1183, 648, 42721 126, 117 AMO 178, 9497 126, 1176 126, 1178 211, 3576 217, 3532 42921 AMO 178, 9497 126, 556 217, 3566 217, 3533 42921 AMA 250, 956, 91, 414 255, 3567 274, 224, 4461 256, 3261 6341 PSD, 94, 814, (2021) 241, 9857 277, 226, 91 257, 3627 24, 4461 257, 3627 24, 4473 GA, 81, 81, (2021) 241, 7817 277, 226, 91 257, 3627 24, 4473 GA, 81, 81, (2021) 241, 7817 277, 1555 270, 3627 24, 4473 GA, 81, 81, (2		CA Bi et al. (2021)	002 0000	010.0240	010 6550	1.0297	10
BAA, Bit al. (2021) 101.2130 205.7122 103.7777 20473 SAA, Bit al. (2021) 109.6280 210.1149 205.7050 2.7165 SAA, Bit al. (2021) 199.6280 210.1149 205.7050 2.7165 BE 184.0766 201.3337 193.6463 4.7731 DE 186.0486 194.1718 185.0220 3.8121 DE 186.0486 194.1718 185.0220 3.8121 DE 186.0487 196.5355 175.0532 6.46651 PSO, Bit al. (2021) 223.8163 266.2553 264.4061 5.8013 OA, Bit al. (2021) 241.6653 269.2553 264.4061 5.8013 OA, Bit al. (2021) 241.7519 271.1409 263.3761 4.4879 SA, Bit al. (2021) 241.7519 277.1552 260.9995 3.8144 DE 21.2673 265.8108 261.2612 3.6145 DE 21.2673 265.8067 4.4879 SA, Bit al. (2021) 316.527 362.8659 342.26367		GA, BI et al. (2021)	203.0229	219.0789	210.002	4.0014	12
GWA, Bir dt. [2021] 196.2802 210.1149 200.7600 2.7165 SMA, Bir dt. [2021] 196.2802 210.1149 200.7600 2.7165 SMA, Bir dt. [2021] 196.0806 195.0718 196.0808 4.2731 DE MAO 178.08064 195.1718 185.9280 3.8121 AMO 178.08064 195.1718 185.9280 3.8121 CALS, Bir dt. [2021] 240.5835 177.646 255.0136 20.2988 AEFA, Bir dt. [2021] 243.5737 272.2864 257.9959 7.3542 PSO, Bir dt. [2021] 243.5737 272.2864 277.0821 2.7613 GOA, Bir dt. [2021] 254.5294 271.1490 248.4373 4.4497 GWA, Bir dt. [2021] 241.5719 272.0850 273.0821 2.7613 SMA, Bir dt. [2021] 241.5719 275.155 260.9966 8.6126 DE 251.2678 265.2818 241.2912 3.448 AMO 222.926 253.8973 4.4891 DE 251.2678		GOA, BI et al. (2021)	181.2130	205.7132	193.7471	5.9105	9
SAA, Bi et al. (2021) 194.02860 210.1148 2067.050 2.7155 DE 184.04965 194.0518 191.7848 2.0882 200 BMA 186.04965 194.0518 191.7838 2.0882 201 BMA 196.05355 175.6532 6.4658 AAFA, Bi et al. (2021) 220.3512 284.2144 285.1616 7.7213 PSO, Bi et al. (2021) 241.6853 266.7055 256.46991 6.3041 (AA, Bi et al. (2021) 241.6853 286.7050 275.0621 2.7613 GA, Bi et al. (2021) 241.7719 275.155 200.90865 8.6126 GA, Bi et al. (2021) 271.1774 275.0621 2.7613 2.7613 SAA, Bi et al. (2021) 241.7619 275.155 200.90865 8.6126 DE 242.7961 260.4494 253.867 4.4871 AMO 242.79751 276.0821 3.3148 AMO 242.79751 276.8131 3.37748 7.7460 AMA 202.917 312.5273		GWO, Bi et al. (2021)	198.1928	206.1991	201.7777	2.0473	10
SMA, Bird. et. (2021) 184,0766 201.3857 193.0488 4.2751 DE 186.498 196.51718 183.2280 3.8121 200 BBMA 228.3146 277.646 256.0136 20.2289 NA 223.8146 277.7646 256.0136 20.2289 PSO, Di et.al. (2021) 243.7771 272.2664 257.0959 7.7213 CA, Di et.al. (2021) 284.5271 277.0660 273.0821 2.7613 CO, Q, Bi et.al. (2021) 284.5271 277.0650 273.0821 2.7613 CO, Q, Bi et.al. (2021) 284.5271 277.0550 20.6965 8.1316 CO, Q, Bi et.al. (2021) 243.2781 277.0550 23.6961 10.0794 SOA, Bi et.al. (2021) 21.2677 352.2585 342.0965 8.1316 DE 25.12675 260.4698 342.076 353.687 4.4871 MAO 22.2697 352.4876 343.4871 4.9673 MA 32.2579 372.6712 353.6987 343.4876 MA <td></td> <td>SOA, Bi et al. (2021)</td> <td>199.3280</td> <td>210.1148</td> <td>205.7050</td> <td>2.7155</td> <td>11</td>		SOA, Bi et al. (2021)	199.3280	210.1148	205.7050	2.7155	11
DE 196.4989 194.3918 191.898 2.0882 200 BEMA 196.4978 196.5955 175.6952 6.4668 AFA, Bi et al. (2021) 23.0322 284.2144 283.1465 7.7213 PSO, Bi et al. (2021) 241.6983 267.25 254.6961 6.5041 (2A, Bi et al. (2021) 243.7737 272.2864 27.9069 7.842 (3A, Bi et al. (2021) 245.5748 277.1400 244.4051 5.8340 (3A, Bi et al. (2021) 265.3718 27.70690 27.30821 2.7613 (3A, Bi et al. (2021) 261.3778 27.70690 27.30821 2.3667 (3MA, Bi et al. (2021) 21.26787 250.8967 3.3146 (AMO) 242.7851 250.4963 3.23786 1.00714 (3MA, Bi et al. (2021) 31.6471 355.2366 342.3936 1.00714 (AMO) 242.9277 355.2366 342.3936 6.5744 (AMO) 32.2379 37.6612 33.66645 6.3107 (AFA, Bi et al. (2021) <t< td=""><td></td><td>SMA, Bi et al. (2021)</td><td>184.0786</td><td>201.3937</td><td>193.6468</td><td>4.2731</td><td>8</td></t<>		SMA, Bi et al. (2021)	184.0786	201.3937	193.6468	4.2731	8
AMO 178,0064 195,1718 183,202 3.1212 200 BEMA 186,478 166,555 175,8552 6.468 AEFA, Bi et al. (2021) 280,323 284,2144 283,1465 7.7213 PSO, Bi et al. (2021) 243,7737 272,2684 257,0959 7.6342 GA, Bi et al. (2021) 286,8786 296,2085 294,4011 5.5300 GOA, Bi et al. (2021) 256,3731 277,0600 273,13821 2.7613 SOA, Bi et al. (2021) 214,17519 275,155 200,9955 6.8126 SOA, Bi et al. (2021) 241,7519 275,155 200,9955 6.8126 DE 221,2078 266,8108 233,6667 4.4667 AMO 242,7813 265,8108 233,2667 4.4667 PSO, Bi et al. (2021) 314,2494 354,3131 337,7758 7.7400 AFA, A Bi et al. (2021) 314,2595 334,26614 332,0705 6.8136 QA, Bi et al. (2021) 339,6598 352,409 313,130 4.4200 <td< td=""><td></td><td>DE</td><td>186.4958</td><td>194.9518</td><td>191.7888</td><td>2.0882</td><td>7</td></td<>		DE	186.4958	194.9518	191.7888	2.0882	7
200BMA196, 8478196, 5355175, 64264, 648MA223, 814275, 77, 764255, 01560.0.209P50, Bi et al. (2021)241, 6883297, 772254, 69916.8041ICA, Bi et al. (2021)243, 7737272, 2864273, 04916.8041ICA, Bi et al. (2021)268, 7784271, 1409243, 78374.479ICA, Bi et al. (2021)268, 7774273, 2864271, 1409243, 7782.7613ICA, Bi et al. (2021)268, 7774276, 58222.4687ICA, Bi et al. (2021)241, 757275, 1255260, 99958.0156ICE251, 2678256, 8108251, 26783.4489ICABIRMA22, 2021352, 23863.4293610.0794AMO222, 7817352, 2386342, 239610.0794PSO, Bi et al. (2021)316, 4617352, 63773.468143.317, 676ICA, Bi et al. (2021)316, 4613337, 7787.7460ICA, Bi et al. (2021)32, 257937, 2621231, 26396.5744ICA, Bi et al. (2021)33, 6682337, 74203.36, 66927.0944ICA, Bi et al. (2021)33, 6683337, 74633.37, 74803.37, 7480ICA, Bi et al. (2021)33, 9676337, 74633.36, 66927.0944ICA, Bi et al. (2021)339, 6574337, 74633.37, 74803.38, 66927.0944ICA, Bi et al. (2021)39, 97, 962632, 7463334, 45454.1294ICA, Bi et al. (2021)39, 97,		AMO	178.0064	195.1718	183.9280	3.8121	3
MA 223,8146 277,646 280,1465 7,7213 AFFA, Bi et al. (2021) 241,0883 269,7025 254,0691 6,8041 ICA, Bi et al. (2021) 241,0883 298,2025 284,4061 5,8340 GA, Bi et al. (2021) 268,7584 271,1409 294,3730 4,4679 GA, Bi et al. (2021) 273,1784 227,0821 2,7013 2,771,0890 273,0821 2,7013 GAA, Bi et al. (2021) 271,1759 277,17562 260,987 2,71852 2,4667 SNA, Bi et al. (2021) 241,7519 277,1852 24,6697 4,4661 AMO 422,7351 260,6168 261,2678 260,459 263,2666 10,0794 AFA, Bi et al. (2021) 314,4911 357,8107 358,645 54,107 PSO, Bi et al. (2021) 314,4911 357,8107 358,645 54,107 PSO, Bi et al. (2021) 314,4914 358,7124 348,6459 7,0944 QAO, Bi et al. (2021) 321,5777 348,8649 333,7045 6,1584 QAO, Bi et al. (200	BBMA	158.8478	186.5355	175.9532	6.4658	1
AFA, Bi et al. (2021) 226,522 284,2144 281,465 7,7213 POD, Bi et al. (2021) 243,777 273,2864 257,9959 7,6342 GA, Bi et al. (2021) 286,7861 296,2853 284,4061 5,8540 GAO, Bi et al. (2021) 286,3731 277,0990 273,0821 2,7613 SAO, Bi et al. (2021) 241,7519 275,1255 260,9965 8,6126 SAO, Bi et al. (2021) 241,7519 275,1255 20,9965 8,6126 DE 251,2678 286,8108 261,2912 3,3148 AMO 242,7951 286,8108 261,2912 3,3148 MA 312,8237 352,2358 342,2036 10,0794 AFA, Bi et al. (2021) 314,2942 354,313 337,778 7,490 ICA, Bi et al. (2021) 321,2577 37,8167 338,8645 4,107 ICA, Bi et al. (2021) 322,2578 332,2737 357,813 337,778 7,7490 ICA, Bi et al. (2021) 332,0222 348,6514 338,6864 4,0494 <		MA	223.8146	277.646	255.0136	20.2298	4
PSO, Br et al. (2021) 241.6893 269.7026 259.969 7.6342 GA, Br et al. (2021) 258.7686 236.2983 284.4061 5.6340 GOA, Bi et al. (2021) 254.5294 271.1409 284.3730 4.4673 GOA, Bi et al. (2021) 254.5294 271.1409 284.3730 4.4673 SOA, Bi et al. (2021) 273.1784 282.3387 277.8522 2.4667 SMA, Bi et al. (2021) 241.7579 275.1255 260.9995 6.6128 DE 251.2678 266.5108 261.2612 3.3148 AMO 242.2975 252.2586 342.2936 10.0794 AEFA, Bi et al. (2021) 316.4191 357.8107 336.8645 8.4107 PSO, Di et al. (2021) 314.2342 343.313 337.7788 7.7460 CA, Bi et al. (2021) 321.6279 372.6212 361.6280 66.5784 GOA, Bi et al. (2021) 339.6863 353.2409 351.6310 4.4290 SAA, Bi et al. (2021) 339.6952 7.0944 305.2665 334.8455		AEFA, Bi et al. (2021)	250.5322	284.2144	263,1465	7.7213	8
IAA Bi et al. (2021) 243.7797 273.2884 257.9869 7.5342 GAA, Bi et al. (2021) 256.7861 296.2853 284.4061 5.8540 GAA, Bi et al. (2021) 256.4294 271.1409 264.3730 4.4679 GWO, Bi et al. (2021) 261.5294 271.1409 277.0500 273.0821 2.7613 SOA, Bi et al. (2021) 241.7519 275.1255 20.09965 8.6126 DE 251.2678 266.4169 253.867 4.4861 DE 251.2678 256.3108 242.2036 10.0754 AFA 181.2621) 314.2942 357.8107 338.8645 8.4107 POO, Bi et al. (2021) 312.5257 357.8103 337.7788 7.7400 ICA, Bi et al. (2021) 330.22579 372.6212 361.2886 6.5794 GA, Bi et al. (2021) 330.22579 372.6212 361.2886 6.5794 GA, Bi et al. (2021) 330.22579 372.6212 361.2886 6.5794 GA, Bi et al. (2021) 330.6268 358.2409 65.1510		PSO Bi et al. (2021)	241 6883	269 7025	254 6991	6 8041	3
SA, Bi et al. (2021) 286,7868 296,2063 294,4061 5,8340 GOA, Bi et al. (2021) 284,5284 271,1499 224,3730 4,4979 GOA, Bi et al. (2021) 273,3731 277,0690 273,0621 2,7613 SOA, Bi et al. (2021) 241,7519 225,3387 277,6522 2,4667 SMA, Bi et al. (2021) 241,7519 226,540 253,0667 4,4611 DE 251,2678 256,108 253,3667 4,4611 AMO 242,27051 260,4549 253,8667 4,4611 AMO 242,7751 252,055 342,2936 10,0794 AEFA, Bi et al. (2021) 316,4191 357,8107 336,0845 8,4107 PSO, Di et al. (2021) 321,2577 372,6212 312,299 6,5794 GA, Bi et al. (2021) 325,2579 372,6212 312,299 6,5794 GA, Bi et al. (2021) 326,0563 334,4455 4,199 SAB, Bi et al. (2021) 337,3928 353,2422 346,6830 4,0648 SAB, Bi et al. (2021)		ICA Rietal (2021)	243 7737	273 2664	257 9959	7 6342	5
GAD, Biret al. (2021) 254.5294 271.1409 264.3730 4.4879 GWO, Biret al. (2021) 265.3731 277.0600 273.0821 2.7613 SAD, Biret al. (2021) 241.7519 275.1255 20.0995 8.6126 SMA, Biret al. (2021) 241.7519 276.1255 250.0995 8.6126 DE 251.2763 256.8108 261.2612 3.3148 AMO 242.7951 260.4549 253.9667 4.4661 250 BEMA 222.2573 352.2358 342.2398 10.0794 ARFA, Bi et al. (2021) 314.25237 358.2358 342.2398 10.0794 PSO, Bi et al. (2021) 321.5577 348.8649 332.0370 6.6376 GA, Bi et al. (2021) 322.2579 372.6212 361.2368 4.0644 SOA, Bi et al. (2021) 339.6638 358.2409 351.6310 4.4290 SOA, Bi et al. (2021) 339.6638 358.2409 351.6310 4.4290 SOA, Bi et al. (2021) 339.6638 358.2409 351.6310 4.4293 <		GA Ri et al. (2021)	240.1101	270.2004	207.3303	5 8240	12
GOV, Stritt al. (2021) 264.5284 211,1429 224.573 4.4619 GWO, Bit al. (2021) 273.3731 277.0690 273.0821 2.7613 SOA, Bit et al. (2021) 241.7519 225.28387 277.6522 2.4687 SMA, Bit et al. (2021) 241.7519 226.4549 253.6867 4.4861 AMO 222.9245 254.7082 235.7813 8.3879 MA 312.5237 332.2338 342.2396 10.0794 AFFA, Bit et al. (2021) 314.2942 354.3313 337.7788 7.7460 PSO, Bit et al. (2021) 321.5577 348.6494 382.0370 6.6376 GA, Bit et al. (2021) 322.2379 372.6212 361.8380 4.0490 SA, Bit et al. (2021) 323.7582 337.7788 7.7460 GA, Bit et al. (2021) 320.2223 349.6514 338.6692 7.0944 GWO, Bit et al. (2021) 337.3628 335.7424 346.8830 4.0490 SA, Bit et al. (2021) 322.9206 342.0495 343.0455 4.1294		COA Bi et al. (2021)	200.7000	290.2900	204.4001	1.4970	12
SOA, Bi et al. (2021) 273.1784 273.0821 273.0821 274.0821 274.0821 SOA, Bi et al. (2021) 231.7784 282.337 277.8822 24.687 SMA, Bi et al. (2021) 241.7519 275.1255 260.9995 8.6126 DE 251.2678 265.8106 261.2712 3.3148 AMO 242.7951 260.4549 253.8667 4.4861 AMO 242.7951 254.062 255.7613 8.9979 MA 312.5237 352.2358 342.2936 10.0794 AEFA, Bi et al. (2021) 314.24242 343.333 377.7788 7.7460 GA, Bi et al. (2021) 322.5279 372.6212 361.2289 6.5794 GOA, Bi et al. (2021) 39.37943 6.3158 382.409 361.6810 4.4290 SOA, Bi et al. (2021) 319.2010 388.8204 329.3968 5.2065 MA 314.4014 388.8204 329.3968 5.2065 MA 194.2011 319.2016 342.4835 341.4855 4.12844			204.0294	271.1409	204.3730	4.4079	9
S0A, bi et al. (2021) 213.1784 228.2387 277.8522 2.0497 SMA, Bi et al. (2021) 215.12678 255.8108 251.2612 3.3146 AMO 242.9245 254.0692 253.8667 4.4861 250 BBMA 222.9245 254.7082 253.7613 8.9879 AEFA, Bi et al. (2021) 316.4191 357.8107 36.8045 8.4107 PSO, Bi et al. (2021) 314.2942 354.3313 337.7788 7.7460 IOA, Bi et al. (2021) 317.3528 353.7242 364.8830 4.0648 GOA, Bi et al. (2021) 337.3528 353.7242 346.8830 4.0648 GOA, Bi et al. (2021) 337.3528 353.7242 346.8830 4.0648 GOA, Bi et al. (2021) 339.6663 382.409 331.6310 4.4290 SMA, Bi et al. (2021) 319.2010 348.9656 4.1284 82429 MO 314.4014 338.6249 331.6310 4.2429 SMA, Bi et al. (2021) 391.557 40.05118 10.8915 MA <td></td> <td>GWO, BI et al. (2021)</td> <td>266.3731</td> <td>277.0690</td> <td>273.0821</td> <td>2.7613</td> <td>10</td>		GWO, BI et al. (2021)	266.3731	277.0690	273.0821	2.7613	10
SMA, Bi et al. (2021) 241.7519 275.1255 260.9995 8.6128 DE 251.2678 255.8168 251.2612 3.3148 AMO 242.7951 260.4549 253.8667 4.4861 BBMA 212.5237 352.2358 342.2936 10.0794 AEFA, Bi et al. (2021) 316.4191 357.8107 336.8645 8.107 PSO, Bi et al. (2021) 321.5577 348.8649 322.0370 6.6376 GA, Bi et al. (2021) 320.2223 349.6514 338.6692 7.0944 GVO, Bi et al. (2021) 337.3628 353.7242 346.8830 4.0694 SOA, Bi et al. (2021) 319.2010 348.0505 339.7043 6.3168 DE 229.29266 342.8853 348.455 4.1294 AMO 71.1592 207.1405 298.7668 10.9117 MA 379.1592 207.1405 298.7668 10.9117 AEFA, Bi et al. (2021) 381.9766 432.1147 406.6118 10.8035 PSO, Bi et al. (2021) 381.9766 <td></td> <td>SOA, Bi et al. (2021)</td> <td>273.1784</td> <td>282.3387</td> <td>277.8522</td> <td>2.4687</td> <td>11</td>		SOA, Bi et al. (2021)	273.1784	282.3387	277.8522	2.4687	11
DE 251/2678 265.8108 261.2612 3.3148 250 BBMA 222.9245 254.7082 235.7813 8.9879 MA 312.25237 352.2358 342.23936 10.0794 AEFA, Bi et al. (2021) 316.4191 337.3107 336.6645 8.4107 PSO, Bi et al. (2021) 316.21577 388.6496 320.3707 6.6376 GA, Bi et al. (2021) 320.2223 349.6514 338.6692 7.0944 GWO, Bi et al. (2021) 320.2223 349.6514 338.6692 7.0944 GWO, Bi et al. (2021) 320.2223 349.6514 338.6692 7.0944 GWO, Bi et al. (2021) 320.2226 353.7242 364.6830 4.0648 SOA, Bi et al. (2021) 329.6638 332.409 351.6310 4.4290 MA 314.4014 338.6204 329.3998 5.2065 MA 314.4014 338.6204 329.3998 5.2065 MA 314.4014 338.6204 329.3998 5.2065 MA 322.9296 <td></td> <td>SMA, Bi et al. (2021)</td> <td>241.7519</td> <td>275.1255</td> <td>260.9995</td> <td>8.6126</td> <td>6</td>		SMA, Bi et al. (2021)	241.7519	275.1255	260.9995	8.6126	6
AMO 242,7951 250,4549 253,8667 4.4861 250 BBMA 222,9245 254,7062 253,7613 38,979 AEFA, Bi et al. (2021) 314,2912 354,2378 352,2358 342,2936 10,0794 ICA, Bi et al. (2021) 314,2942 354,3313 337,7788 7,7460 ICA, Bi et al. (2021) 321,5577 348,8649 332,0370 6,6376 ICA, Bi et al. (2021) 320,2223 349,6514 338,6692 7,9944 GOA, Bi et al. (2021) 339,96638 353,7242 361,6310 4,4290 SOA, Bi et al. (2021) 319,2010 348,9050 339,7043 6,3158 JOB BEMA 229,2926 322,8365 34,8455 4,1294 JOB 314,4014 338,6204 239,998 5,2065 JOB BEMA 379,1592 425,7837 413,7186 13,8915 JOB BEMA 39,0968 412,3079 406,6118 10,8839 JOB BEMA 39,0936 415,8944 4		DE	251.2678	265.8108	261.2612	3.3148	7
250 BIMA 22.29245 254.7062 25.7713 8.9379 MA 212.5237 352.5237 352.5258 324.2936 10.0794 AEFA, Bi et al. (2021) 316.4191 357.8107 336.8645 8.4107 ICA, Bi et al. (2021) 314.2942 364.3313 337.7788 7.7460 ICA, Bi et al. (2021) 321.5577 348.8649 332.0370 6.6376 GWO, Bi et al. (2021) 320.2223 349.6514 388.6692 7.0944 GWO, Bi et al. (2021) 339.6638 352.7242 346.8630 4.0648 SMA, Bi et al. (2021) 39.92043 388.52409 351.610 4.4290 SMA, Bi et al. (2021) 39.92043 348.655 334.8655 4.1294 AEFA, All et al. (2021) 39.92043 348.6504 329.3998 5.2065 SMA ST5.7485 320.7405 298.7666 10.9117 MA 379.1592 425.737 413.7166 13.8915 AEFA, Bi et al. (2021) 39.39264 4425.3140 412.8644 8.6242<		AMO	242.7951	260.4549	253.8667	4.4861	2
MA 312.5237 352.2358 342.2936 10.0794 AEFA, Bi et al. (2021) 316.4191 357.8107 336.8645 8.4107 PSO, Bi et al. (2021) 321.5577 348.8649 332.0370 6.6376 GA, Bi et al. (2021) 320.2223 349.6514 338.6692 7.0944 GWO, Bi et al. (2021) 337.6828 353.7242 346.8830 4.0948 SOA, Bi et al. (2021) 339.6638 358.2409 351.6310 4.4290 SMA, Bi et al. (2021) 319.2010 348.9050 339.7043 6.3158 DE 322.9296 322.57837 413.7186 1.38915 AMO 319.766 432.1147 406.6118 1.08638 SOA, Bi et al. (2021) 381.9766 432.1147 406.6118 1.08638 AEFA, Bi et al. (2021) 383.9086 415.8944 400.3720 8.5996 GA, Bi et al. (2021) 422.2974 448.4215 437.9276 5.7820 GA, Bi et al. (2021) 422.3976 410.6107 40.02.574 8.2339	250	BBMA	222.9245	254.7082	235.7813	8.9879	1
AEFA, Bi et al. (2021) 316.4191 357.8107 336.845 8.4107 PSO, Bi et al. (2021) 314.2942 354.3313 337.7788 7.7460 IOA, Bi et al. (2021) 321.5577 386.8649 322.0370 6.6376 GA, Bi et al. (2021) 322.2579 372.6212 381.2898 6.5794 GA, Bi et al. (2021) 337.3628 353.7242 346.8830 4.0648 GWO, Bi et al. (2021) 339.6638 358.2409 351.6310 4.4290 SMA, Bi et al. (2021) 339.2010 348.8050 339.7043 6.3158 DE 322.9296 342.6385 334.8455 4.1294 MA 379.1592 425.7837 413.7186 13.8915 MA 379.1592 425.7837 413.7186 13.8915 AEFA, Bi et al. (2021) 390.3274 425.3140 412.8644 8.6242 IOA, Bi et al. (2021) 382.956 421.3079 408.2574 8.2339 GOA, Bi et al. (2021) 438.2964 421.3079 408.2574 8.2339		MA	312.5237	352.2358	342.2936	10.0794	9
PSO, Bi et al. (2021) 314.2942 364.3313 337.7788 7.7460 ICA, Bi et al. (2021) 321.5577 348.8049 332.0370 6.6376 GA, Bi et al. (2021) 352.2579 372.6212 361.2299 6.5794 GOA, Bi et al. (2021) 337.3628 356.37242 348.8692 7.0944 GWO, Bi et al. (2021) 339.6638 356.2409 351.6310 4.4290 SMA, Bi et al. (2021) 319.2010 348.9050 339.7043 6.3158 DE 322.2926 342.6385 338.455 4.1294 AMO 314.4014 338.6204 329.3998 5.2065 MA 77.1546 320.7405 298.7668 10.9117 MA 373.1592 425.7837 113.7168 13.8915 AEFA, Bi et al. (2021) 390.3274 425.3140 412.8644 8.6242 ICA, Bi et al. (2021) 390.3274 425.3140 412.8644 8.6242 ICA, Bi et al. (2021) 383.9066 415.8944 400.3770 8.58996 GAD, Bi et al. (AEFA, Bi et al. (2021)	316.4191	357.8107	336.8645	8.4107	5
ICA, Bi et al. (2021) 321.5577 348.8649 332.0370 6.6376 GA, Bi et al. (2021) 352.2579 372.6212 361.2289 6.5794 GOA, Bi et al. (2021) 337.3628 353.7242 346.8830 4.0648 GWO, Bi et al. (2021) 339.6638 356.2409 351.6310 4.4290 SMA, Bi et al. (2021) 339.6638 356.2409 351.6310 4.4290 MO 314.4014 338.6620 339.7033 6.63158 DE 322.9296 342.6385 348.8455 4.1294 AMO 371.102 482.050 339.7045 298.7668 10.9117 MA 379.1592 425.7837 413.7196 138.915 AEFA, Bi et al. (2021) 390.3274 425.7437 413.7196 138.915 GA, Bi et al. (2021) 390.3274 425.7437 413.7196 138.915 GA, Bi et al. (2021) 383.9066 415.8944 400.3720 8.5896 GA, Bi et al. (2021) 422.2974 448.4215 437.9276 5.7820		PSO. Bi et al. (2021)	314.2942	354.3313	337.7788	7,7460	6
GA, Bl et al. (2021) 352,2579 372,6212 361,2289 6,5794 GOA, Bl et al. (2021) 320,2223 349,6614 338,6692 7,0944 GWO, Bl et al. (2021) 339,6638 353,7242 366,8830 4,0648 SOA, Bl et al. (2021) 319,0638 358,2409 351,6310 4,4290 SMA, Bl et al. (2021) 319,2010 348,9050 339,7043 6,3158 DE 322,9296 342,6385 343,48455 4,1294 AMO 314,4014 338,6204 329,3998 5,2065 300 BBMA 275,7495 320,7405 288,7668 10,9117 MA 379,1592 425,7837 413,7186 13,8915 AEFA, Bl et al. (2021) 381,9766 452,1147 406,6118 10,8638 PSO, El et al. (2021) 383,9086 415,8944 400,3720 8,5896 GA, Bl et al. (2021) 422,2974 448,4215 437,9276 5,7820 GOA, Bl et al. (2021) 416,0361 425,4912 420,2078 2,5851		ICA. Bi et al. (2021)	321.5577	348.8649	332.0370	6.6376	3
GOA, Bi et al. (2021) 320.223 349.6514 336.6692 7.0944 GWO, Bi et al. (2021) 337.9628 353.7242 346.8830 4.0648 SOA, Bi et al. (2021) 339.6638 358.2409 351.6510 4.4290 SMA, Bi et al. (2021) 319.2010 348.9050 339.7043 6.3158 DE 322.9296 342.6385 334.8455 4.1294 AMO 314.4014 338.6204 329.3998 5.2065 300 BBMA 275.7495 320.7405 298.7668 10.9117 MA 379.1592 425.7837 413.7186 13.8915 AEFA, Bi et al. (2021) 389.0966 415.8944 400.3720 8.5896 GA, Bi et al. (2021) 388.2968 421.3079 408.2574 8.2339 GOA, Bi et al. (2021) 422.2974 448.4215 437.9276 5.7820 GOA, Bi et al. (2021) 428.2912 420.2078 2.5851 GOA, Bi et al. (2021) 416.0361 425.4912 420.2078 2.5861 SOA, Bi et al. (2021		GA Bi et al. (2021)	352 2579	372 6212	361 2289	6 5794	12
GVA, Di et al. (2021) 307,3628 353,7242 346,8330 4,0648 SOA, Bi et al. (2021) 339,6638 358,2409 351,6310 4,4290 SMA, Bi et al. (2021) 319,2010 348,9050 339,7043 6,3158 DE 322,9296 342,6385 348,455 4,1294 AMO 314,4014 386,6204 329,3998 5,2065 300 BBMA 275,7485 320,7405 298,7668 10,9117 MA 379,1592 425,7837 413,7186 13,8815 AEFA, Bi et al. (2021) 381,9766 432,1147 406,6118 10,8638 PSO, Bi et al. (2021) 383,9086 415,8944 400,3720 8,5896 GA, Bi et al. (2021) 422,2974 448,4215 437,9276 5,7820 GOA, Bi et al. (2021) 426,6951 425,4912 420,2078 2,58651 SOA, Bi et al. (2021) 446,6552 424,1153 414,6620 4,0100 SMA, Bi et al. (2021) 446,6552 424,1153 414,6620 4,0100 <		COA Riotal (2021)	320 2223	240.6514	338 6602	7 0044	7
SOA, Bi et al. (2021) 339,6638 351,242 541,050 4,0290 SMA, Bi et al. (2021) 319,2010 348,9050 339,7043 6,3158 DE 322,9296 342,6385 334,8455 4,1294 MOO 314,4014 338,6204 329,3988 5,2065 300 BEMA 275,7485 320,7405 298,7668 10,9117 MA 379,1592 425,7337 413,7186 13,8915 AEFA, Bi et al. (2021) 390,3274 425,3140 412,8644 8,6242 ICA, Bi et al. (2021) 383,9086 415,8944 400,3720 8,5896 GOA, Bi et al. (2021) 388,2968 421,3079 408,2574 8,2339 GWO, Bi et al. (2021) 446,6651 444,215 47,220 4,0100 SMA, Bi et al. (2021) 446,6652 442,115 414,6620 4,0100 SMA, Bi et al. (2021) 391,2315 417,1096 404,5279 6,1692 DE 381,7567 410,6107 402,4801 5,3663 AMO 390,2933 413,9668 401,9473 5,3906 S50		GWO Bi et al. (2021)	227 2629	252 7042	346 9930	1.0044	10
SOA, Bi et al. (2021) 339.0635 368.2409 351.6310 4.4290 SMA, Bi et al. (2021) 319.2010 348.9050 339.7043 6.3158 DE 322.9296 342.6385 334.8455 4.1294 AMO 314.4014 338.6204 329.3998 5.2065 300 BBMA 275.7485 320.7405 298.7666 10.9117 MA 379.1592 425.7837 413.7186 13.8915 AEFA, Bi et al. (2021) 381.9766 432.1147 406.6118 10.8638 PSO, Bi et al. (2021) 383.9086 415.8944 400.3720 8.5986 GA, Bi et al. (2021) 388.2968 421.3079 408.2574 8.2339 GWO, Bi et al. (2021) 404.6652 424.1153 414.6620 4.0100 SMA, Bi et al. (2021) 404.6652 424.1153 414.6620 4.0100 SMA, Bi et al. (2021) 404.6652 424.1153 414.6620 4.0100 SMA, Bi et al. (2021) 404.6652 424.1153 414.6620 4.0100		GWO, BI et al. (2021)	000.0000	050.7242	340.0030	4.0040	10
SMA, Bi et al. (2021) 319.2010 349.050 339.7043 6.3158 DE 322.9296 342.6355 348.455 4.1294 AMO 314.4014 338.6204 329.3998 5.2065 300 BBMA 275.7485 20.7405 298.7668 10.9117 MA 379.1592 425.7837 413.7186 13.8915 AEFA, Bi et al. (2021) 390.3274 425.3140 412.8644 8.6242 ICA, Bi et al. (2021) 383.9086 415.8944 400.3720 8.5896 GA, Bi et al. (2021) 428.968 421.3079 408.2574 8.2339 GWO, Bi et al. (2021) 404.6652 424.1153 414.6620 4.0100 SMA, Bi et al. (2021) 404.6652 421.153 414.6620 4.0100 SMA, Bi et al. (2021) 404.6652 424.1153 414.6620 4.0100 SMA, Bi et al. (2021) 391.2315 417.1096 404.5279 6.1692 DE 381.7567 410.6107 402.4801 5.3663 AMO		SOA, BI et al. (2021)	339.6638	358.2409	351.6310	4.4290	11
DE 322.9296 342.6385 334.8455 4.1294 AMO 314.4014 338.6204 329.3998 5.2065 300 BBMA 275.7485 320.7405 298.7668 10.9117 MA 379.1592 425.7837 413.7186 13.8915 AEFA, Bi et al. (2021) 381.9766 432.1147 406.6118 10.8638 PSO, Bi et al. (2021) 383.9086 415.8944 400.3720 8.5896 GA, Bi et al. (2021) 388.2968 421.3079 408.2574 8.2339 GOA, Bi et al. (2021) 404.6652 424.1153 414.6620 4.0100 SOA, Bi et al. (2021) 404.6652 424.1153 414.6620 4.0100 SMA, Bi et al. (2021) 404.6652 424.1153 414.6620 4.0100 SMA, Bi et al. (2021) 404.6652 424.1153 414.6620 4.0100 SMA, Bi et al. (2021) 404.6652 501.0686 488.1678 14.4075 AMO 300.6316 379.8724 356.8802 11.8212 MA		SMA, Bi et al. (2021)	319.2010	348.9050	339.7043	6.3158	8
AMO 314.4014 338.6204 329.3998 5.2065 300 BBMA 275.7485 320.7405 298.7668 10.9117 MA 379.1592 425.7837 413.7186 13.8915 AEFA, Bi et al. (2021) 381.9766 432.1147 406.6118 10.8638 PSO, Bi et al. (2021) 390.3274 425.3140 412.8644 8.6242 ICA, Bi et al. (2021) 383.9086 415.8944 400.3720 8.5896 GA, Bi et al. (2021) 422.974 448.4215 437.9276 5.7820 GVA, Bi et al. (2021) 416.0561 425.4912 420.2078 2.5881 GWO, Bi et al. (2021) 404.6652 424.1153 414.66620 4.0100 SMA, Bi et al. (2021) 404.6652 424.1153 414.6620 4.0100 SMA, Bi et al. (2021) 391.2315 417.1096 404.5279 6.1692 DE 381.7567 410.6107 402.4801 5.3806 AFA, Bi et al. (2021) 391.2315 417.1096 404.5279 6.1692		DE	322.9296	342.6385	334.8455	4.1294	4
300 BBMA 275.7485 320.7405 298.7668 10.9117 MA 379.1592 425.7837 413.7186 13.8915 AEFA, Bi et al. (2021) 390.3274 425.7837 413.7186 13.8915 PSO, Bi et al. (2021) 390.3274 425.3140 412.8644 8.6242 ICA, Bi et al. (2021) 383.9086 415.8944 400.3720 8.5896 GA, Bi et al. (2021) 422.2974 448.4215 437.9276 5.7820 GOA, Bi et al. (2021) 416.0361 425.4912 420.2078 2.5851 SOA, Bi et al. (2021) 404.6652 424.1153 414.6620 4.0100 SMA, Bi et al. (2021) 391.2315 417.1096 404.5279 6.1692 DE 381.7567 410.6107 402.4801 5.3906 350 BBMA 30.6316 379.8724 356.8802 11.8212 MA 452.2005 501.0686 488.1878 14.4075 ABFA, Bi et al. (2021) 456.7770 493.9439 475.2845 9.5855		AMO	314.4014	338.6204	329.3998	5.2065	2
MA 379.1592 425.7837 413.7186 13.8915 AEFA, Bi et al. (2021) 381.9766 432.1147 406.6118 10.8638 PSO, Bi et al. (2021) 390.3274 425.3140 412.8644 8.6242 ICA, Bi et al. (2021) 383.9086 415.8944 400.3720 8.5896 GA, Bi et al. (2021) 422.2974 448.4215 437.9276 5.7820 GOA, Bi et al. (2021) 388.2968 421.3079 408.2574 8.2339 GWO, Bi et al. (2021) 416.0361 425.4912 420.2078 2.5851 SOA, Bi et al. (2021) 404.6652 424.1153 414.6620 4.0100 SMA, Bi et al. (2021) 404.6652 424.1153 414.6620 4.0100 SMA, Bi et al. (2021) 404.6652 424.1153 414.6620 4.0100 SMA 390.2933 413.9668 401.9473 5.3906 AMO 390.2933 413.9668 401.9473 5.3906 JEA, Bi et al. (2021) 461.6761 501.5019 483.2021 9.3857	300	BBMA	275.7485	320.7405	298.7668	10.9117	1
AEFA, Bi et al. (2021) 381.9766 432.1147 406.6118 10.8638 PSO, Bi et al. (2021) 390.3274 425.3140 412.8644 8.6242 ICA, Bi et al. (2021) 483.9086 415.8944 400.3720 8.5896 GA, Bi et al. (2021) 422.2974 448.4215 437.9276 5.7820 GOA, Bi et al. (2021) 388.2968 421.3079 408.2574 8.2339 GWO, Bi et al. (2021) 416.0361 425.4912 420.2078 2.5851 SOA, Bi et al. (2021) 404.6652 424.1153 414.6620 4.0100 SMA, Bi et al. (2021) 391.2315 417.1096 404.5279 6.1692 DE 381.7567 410.6107 402.4801 5.3663 AMO 390.2933 413.9668 401.9473 5.3906 350 BBMA 30.6316 379.8724 356.8022 11.8212 MA 452.2005 501.0686 488.1878 14.4075 AEFA, Bi et al. (2021) 456.7770 493.9439 475.2845 9.5585		MA	379.1592	425.7837	413.7186	13.8915	9
PSO, Bi et al. (2021) 390.3274 425.3140 412.8644 8.6242 ICA, Bi et al. (2021) 383.9086 415.8944 400.3720 8.5896 GA, Bi et al. (2021) 422.2974 448.4215 437.9276 5.7820 GOA, Bi et al. (2021) 416.0361 425.4912 420.2078 2.5851 SOA, Bi et al. (2021) 416.0361 425.4912 420.2078 2.5851 SOA, Bi et al. (2021) 404.6652 424.1153 414.6620 4.0100 SMA, Bi et al. (2021) 391.2315 417.1096 404.5279 6.1692 DE 381.7667 410.6107 402.4801 5.3663 AMO 390.2933 413.9668 401.9473 5.3906 350 BBMA 30.6316 79.8724 366.802 11.8212 MA 452.2005 501.0686 488.1878 14.4075 AEFA, Bi et al. (2021) 451.6770 493.9439 475.2845 9.5895 GA, Bi et al. (2021) 456.7770 493.9439 475.2845 9.5895		AEFA, Bi et al. (2021)	381.9766	432.1147	406.6118	10.8638	6
ICA, Bi et al. (2021) 383.9086 415.8944 400.3720 8.5896 GA, Bi et al. (2021) 422.2974 448.4215 437.9276 5.7820 GOA, Bi et al. (2021) 388.2968 421.3079 408.2574 8.2339 GWO, Bi et al. (2021) 416.0361 425.4912 420.2078 2.5851 SOA, Bi et al. (2021) 404.6652 424.1153 414.6620 4.0100 SMA, Bi et al. (2021) 391.2315 417.1096 404.5279 6.1692 DE 381.7567 410.6107 402.4801 5.3663 AMO 390.2933 413.9668 401.9473 5.3906 350 BBMA 330.6316 379.8724 356.8802 11.8212 MA 452.2005 501.0686 488.1878 14.4075 AEFA, Bi et al. (2021) 461.6761 501.5019 483.2021 9.3857 PSO, Bi et al. (2021) 453.2706 526.2063 514.2878 8.1990 GOA, Bi et al. (2021) 456.7770 433.9439 475.2845 9.5585		PSO, Bi et al. (2021)	390.3274	425.3140	412.8644	8.6242	8
GA, Bi et al. (2021) 422.2974 448.4215 437.9276 5.7820 GOA, Bi et al. (2021) 388.2968 421.3079 408.2574 8.2339 GWO, Bi et al. (2021) 416.0361 425.4912 420.2078 2.5851 SOA, Bi et al. (2021) 404.6652 424.1153 414.6620 4.0100 SMA, Bi et al. (2021) 391.2315 417.1096 404.5279 6.1692 DE 381.7567 410.6107 402.4801 5.3663 AMO 390.2933 413.9668 401.9473 5.3906 350 BEMA 330.6316 379.8724 356.8802 11.8212 MA 452.2005 501.0666 488.1878 14.4075 AEFA, Bi et al. (2021) 461.6761 501.5019 483.2021 9.3857 PSO, Bi et al. (2021) 456.7770 493.9439 475.2845 9.5585 GA, Bi et al. (2021) 451.804 494.6949 479.9414 8.0381 GWO, Bi et al. (2021) 461.8404 494.6949 479.9414 8.0381		ICA. Bi et al. (2021)	383.9086	415.8944	400.3720	8.5896	2
GOA, Bi et al. (2021) 388.2968 421.3079 408.2574 8.2339 GWO, Bi et al. (2021) 416.0361 425.4912 420.2078 2.5851 SOA, Bi et al. (2021) 404.6652 424.1153 414.6620 4.0100 SMA, Ei et al. (2021) 391.2315 417.1096 404.5279 6.1692 DE 381.7567 410.6107 402.4801 5.3663 AMO 390.2933 413.9668 401.9473 5.3906 350 BBMA 30.6316 379.8724 356.8802 11.8212 MA 452.2005 501.0686 488.1878 14.4075 AEFA, Bi et al. (2021) 461.6761 501.5019 483.2021 9.3857 PSO, Bi et al. (2021) 456.7770 493.9439 475.2845 9.5585 GA, Bi et al. (2021) 494.1726 526.2063 514.2878 8.1990 GOA, Bi et al. (2021) 494.1726 526.2063 514.2878 8.1990 GOA, Bi et al. (2021) 496.95365 498.2843 490.9486 6.2352		GA. Bi et al. (2021)	422,2974	448,4215	437,9276	5,7820	12
GWO, Bi et al. (2021) 416.0361 425.4912 420.2078 2.5851 SOA, Bi et al. (2021) 404.6652 424.1153 414.6620 4.0100 SMA, Bi et al. (2021) 391.2315 417.1096 404.5279 6.1692 DE 381.7567 410.6107 402.4801 5.3663 AMO 390.2933 413.9668 401.9473 5.3906 350 BBMA 330.6316 379.8724 356.8802 11.8212 MA 452.2005 501.0686 488.1878 14.4075 AEFA, Bi et al. (2021) 461.6761 501.5019 483.2021 9.3857 PSO, Bi et al. (2021) 456.7770 493.9439 475.2845 9.5585 GA, Bi et al. (2021) 456.7770 493.9439 475.2845 9.5585 GA, Bi et al. (2021) 456.7770 493.9439 475.2845 9.5585 GA, Bi et al. (2021) 456.3296 502.2586 495.3422 3.6271 GOA, Bi et al. (2021) 461.8404 494.6949 479.9414 8.0381 GWO, Bi et al. (2021) 465.3296 502.2586 495.3422 3.6271 <td></td> <td>GOA Bietal (2021)</td> <td>388 2968</td> <td>421.3079</td> <td>408 2574</td> <td>8 2339</td> <td>7</td>		GOA Bietal (2021)	388 2968	421.3079	408 2574	8 2339	7
SOA, Bi et al. (2021) 404.6652 424.1153 414.6620 4.0100 SMA, Bi et al. (2021) 391.2315 417.1096 404.5279 6.1692 DE 381.7567 410.6107 402.4801 5.3663 AMO 390.2933 413.9668 401.9473 5.3906 350 BBMA 330.6316 379.8724 356.8802 11.8212 MA 452.2005 501.0686 488.1878 14.4075 AEFA, Bi et al. (2021) 461.6761 501.5019 483.2021 9.3857 PSO, Bi et al. (2021) 456.7770 493.9439 475.2845 9.5585 GA, Bi et al. (2021) 461.8404 494.6949 479.9414 8.0381 GWO, Bi et al. (2021) 485.3296 502.2586 495.3422 3.6271 GOA, Bi et al. (2021) 485.3296 502.2586 495.3422 3.6271 GOA, Bi et al. (2021) 485.3296 502.2586 495.3422 3.6271 GOA, Bi et al. (2021) 485.3296 502.2586 495.3422 3.6271 SOA, Bi et al. (2021) 461.8404 494.263 483.9335 7.5615 <td></td> <td>GWO Bi et al. (2021)</td> <td>416.0361</td> <td>425.4912</td> <td>420 2078</td> <td>2 5851</td> <td>11</td>		GWO Bi et al. (2021)	416.0361	425.4912	420 2078	2 5851	11
SOA, Bi et al. (2021) 404.0002 424.1103 414.0020 4.0100 SMA, Bi et al. (2021) 391.2315 417.1096 404.5279 6.1692 DE 381.7567 410.6107 402.4801 5.3663 AMO 390.2933 413.9668 401.9473 5.3906 350 BBMA 330.6316 379.8724 356.8802 11.8212 MA 452.2005 501.0686 488.1878 14.4075 AEFA, Bi et al. (2021) 461.6761 501.5019 483.2021 9.3857 PSO, Bi et al. (2021) 456.7770 493.9439 475.2845 9.5585 GA, Bi et al. (2021) 456.7770 493.9439 475.2845 9.5585 GA, Bi et al. (2021) 461.8404 494.6949 479.9414 8.0381 GWO, Bi et al. (2021) 485.3296 502.2586 495.3422 3.6271 SOA, Bi et al. (2021) 485.336 502.2586 495.3422 3.6271 GOA, Bi et al. (2021) 469.5365 498.2843 490.9486 6.2352 SMA 469.6158 494.4263 483.9335 7.5615 <t< td=""><td></td><td>SOA Bi et al. (2021)</td><td>404 6652</td><td>420.4012</td><td>414 6620</td><td>4.0100</td><td>10</td></t<>		SOA Bi et al. (2021)	404 6652	420.4012	414 6620	4.0100	10
SMA, Bi et al. (2021) 391.2353 417.1096 404.5279 6.1692 DE 381.7567 410.6107 402.4801 5.3663 AMO 390.2933 413.9668 401.9473 5.3906 350 BBMA 330.6316 379.8724 356.8802 11.8212 MA 452.2005 501.0686 488.1878 14.4075 AEFA, Bi et al. (2021) 461.6761 501.5019 483.2021 9.3857 PSO, Bi et al. (2021) 453.2908 498.2213 484.1515 10.7357 ICA, Bi et al. (2021) 456.7770 493.9439 475.2845 9.5585 GA, Bi et al. (2021) 494.1726 526.2063 514.2878 8.1990 GOA, Bi et al. (2021) 461.8404 494.6949 479.9414 8.0381 GWO, Bi et al. (2021) 485.3296 502.2586 495.3422 3.6271 SOA, Bi et al. (2021) 485.3296 502.2586 495.3422 3.6271 SOA, Bi et al. (2021) 469.5365 498.2843 490.9486 6.2352 SMA 466.6158 494.4263 483.9335 7.5615		SOA, Di et al. (2021)	404.0002	424.1100	414.0020	4.0100	10
DE 381.7567 410.6107 402.4801 5.3663 AMO 390.2933 413.9668 401.9473 5.3906 350 BBMA 330.6316 379.8724 356.8802 11.8212 MA 452.2005 501.0686 488.1878 14.4075 AEFA, Bi et al. (2021) 461.6761 501.5019 483.2021 9.3857 PSO, Bi et al. (2021) 453.2908 498.2213 484.1515 10.7357 ICA, Bi et al. (2021) 456.7770 493.9439 475.2845 9.5585 GA, Bi et al. (2021) 461.804 494.6949 479.9414 8.0381 GWO, Bi et al. (2021) 461.804 494.6949 479.9414 8.0381 GWO, Bi et al. (2021) 465.3296 502.2586 495.3422 3.6271 SOA, Bi et al. (2021) 469.5365 498.2843 490.9486 6.2352 SMA 466.6158 494.4263 483.9335 7.5615 DE 469.6890 487.5686 480.7679 4.0358 AMO 46		SMA, BI et al. (2021)	391.2315	417.1096	404.5279	6.1692	5
AMO 390.2933 413.9668 401.9473 5.3906 350 BBMA 330.6316 379.8724 356.8802 11.8212 MA 452.2005 501.0686 488.1878 14.4075 AEFA, Bi et al. (2021) 461.6761 501.5019 483.2021 9.3857 PSO, Bi et al. (2021) 453.2908 498.2213 484.1515 10.7357 ICA, Bi et al. (2021) 456.7770 493.9439 475.2845 9.5585 GA, Bi et al. (2021) 494.1726 526.2063 514.2878 8.1990 GOA, Bi et al. (2021) 461.8404 494.6949 479.9414 8.0381 GWO, Bi et al. (2021) 485.3296 502.2586 495.3422 3.6271 SOA, Bi et al. (2021) 469.5365 498.2843 490.9486 6.2352 SMA 466.6158 494.4263 483.9335 7.5615 DE 469.6890 487.5686 480.7679 4.0358 AMO 460.0170 482.6614 473.4664 5.3265		DE	381.7567	410.6107	402.4801	5.3663	4
350 BBMA 330.6316 379.8724 356.8802 11.8212 MA 452.2005 501.0686 488.1878 14.4075 AEFA, Bi et al. (2021) 461.6761 501.5019 483.2021 9.3857 PSO, Bi et al. (2021) 453.2908 498.2213 484.1515 10.7357 ICA, Bi et al. (2021) 456.7770 493.9439 475.2845 9.5585 GA, Bi et al. (2021) 456.7770 493.9439 475.2845 9.5585 GA, Bi et al. (2021) 494.1726 526.2063 514.2878 8.1990 GOA, Bi et al. (2021) 461.8404 494.6949 479.9414 8.0381 GWO, Bi et al. (2021) 461.8404 494.6949 479.9414 8.0381 GWO, Bi et al. (2021) 469.5365 498.2843 490.9486 6.2352 SOA, Bi et al. (2021) 469.5365 498.2843 490.9486 6.2352 SMA 466.6158 494.4263 483.9335 7.5615 DE 469.6890 487.5686 480.7679 4.0358		AMO	390.2933	413.9668	401.9473	5.3906	3
MA 452.2005 501.0686 488.1878 14.4075 AEFA, Bi et al. (2021) 461.6761 501.5019 483.2021 9.3857 PSO, Bi et al. (2021) 453.2908 498.2213 484.1515 10.7357 ICA, Bi et al. (2021) 456.7770 493.9439 475.2845 9.5585 GA, Bi et al. (2021) 494.1726 526.2063 514.2878 8.1990 GOA, Bi et al. (2021) 461.8404 494.6949 479.9414 8.0381 GWO, Bi et al. (2021) 485.3296 502.2586 495.3422 3.6271 SOA, Bi et al. (2021) 469.5365 498.2843 490.9486 6.2352 SOA, Bi et al. (2021) 469.5365 498.2843 490.9486 6.2352 SOA, Bi et al. (2021) 469.5365 494.4263 483.9335 7.5615 DE 469.6890 487.5686 480.7679 4.0358 AMO 460.0170 482.6614 473.4664 5.3265	350	BBMA	330.6316	379.8724	356.8802	11.8212	1
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ICA, Bi et al. (2021)456.7770493.9439475.28459.5585GA, Bi et al. (2021)494.1726526.2063514.28788.1990GOA, Bi et al. (2021)461.8404494.6949479.94148.0381GWO, Bi et al. (2021)485.3296502.2586495.3422 3.6271 SOA, Bi et al. (2021)469.5365498.2843490.94866.2352SMA466.6158494.4263483.93357.5615DE469.6890487.5686480.76794.0358AMO460.0170482.6614473.46645.3265		PSO, Bi et al. (2021)	453.2908	498.2213	484.1515	10.7357	8
GA, Bi et al. (2021)494.1726526.2063514.28788.1990GOA, Bi et al. (2021)461.8404494.6949479.94148.0381GWO, Bi et al. (2021)485.3296502.2586495.3422 3.6271 SOA, Bi et al. (2021)469.5365498.2843490.94866.2352SMA466.6158494.4263483.93357.5615DE469.6890487.5686480.76794.0358AMO460.0170482.6614473.46645.3265		ICA, Bi et al. (2021)	456.7770	493.9439	475.2845	9.5585	3
GOA, Bi et al. (2021) 461.8404 494.6949 479.9414 8.0381 GWO, Bi et al. (2021) 485.3296 502.2586 495.3422 3.6271 SOA, Bi et al. (2021) 469.5365 498.2843 490.9486 6.2352 SMA 466.6158 494.4263 483.9335 7.5615 DE 469.6890 487.5686 480.7679 4.0358 AMO 460.0170 482.6614 473.4664 5.3265		GA, Bi et al. (2021)	494.1726	526.2063	514.2878	8.1990	12
GWO, Bi et al. (2021) 485.3296 502.2586 495.3422 3.6271 SOA, Bi et al. (2021) 469.5365 498.2843 490.9486 6.2352 SMA 466.6158 494.4263 483.9335 7.5615 DE 469.6890 487.5686 480.7679 4.0358 AMO 460.0170 482.6614 473.4664 5.3265		GOA. Bi et al. (2021)	461,8404	494 6949	479 9414	8.0381	4
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AMO 460.0170 482.6614 473.4664 5.3265		JIVIA	400.0158	494.4203	403.9335	1.0010	1
AMU 460.0170 482.6614 473.4664 5.3265			409.0890	487.5686	480.7679	4.0358	5
		AMO	460.0170	482.6614	473.4664	5.3265	2

TABLE 3	(Continued)	Experimental	results for	the twelve	algorithms for	150, 200,	250, 300	0, 350, and 400	points.
	(001101000)		10000100		agona no	,,	200, 00.	, 000, and 100	000000

Points	Algorithms	Best	Worst	Mean	Std	Rank
400	BBMA	382.1640	438.9316	415.9261	13.1962	1
	MA	508.5346	569.2624	551.9432	18.5577	4
	AEFA, Bi et al. (2021)	533.7028	575.2738	558.5251	10.7157	8
	PSO , Bi et al. (2021)	535.9726	563.4369	552.9052	7.1746	5
	ICA, Bi et al. (2021)	527.6904	576.9956	549.9101	11.2322	3
	GA, Bi et al. (2021)	562.2246	601.2813	586.7195	7.9634	12
	GOA, Bi et al. (2021)	533.5131	573.5504	555.9482	10.8102	7
	GWO, Bi et al. (2021)	558.2885	576.4934	568.7354	4.3849	10
	SOA, Bi et al. (2021)	562.1377	580.3801	575.1273	4.3925	11
	SMA, Bi et al. (2021)	545.4407	577.0593	561.7902	8.3622	9
	DE	534.0305	561.5491	554.6098	4.9569	6
	AMO	530.8524	552.8364	543.4986	5.3476	2

The optimal values are shown in bold.

runs are obtained. **Table 1** gives the best value, worst value, mean value, standard deviation, and the ranking of mean value. The bold data indicate that it is the best value of the twelve algorithms. **Figure 3** shows the convergence curves in these four situations, **Figure 4** shows the ANOVA test results, **Figure 5** shows the fitness values for 30 runs, and **Figure 12A–D** show the minimum spanning tree for four low-dimensional cases, where "ROOT" is the root of the minimum spanning tree. **Figure 13A** shows the average running time of 30 runs of 12 algorithms in four dimensions. Finally, the Wilcoxon rank-sum non-parametric test results in low-dimensional cases are shown in **Table 2**.

The comparison results for 25 points are shown in **Table 1**. BBMA performs best in the best, worst, and mean value, but its standard deviation is 1.0202 which is worse than that of AMO, while the algorithm with the worst performance is GA. **Figure 3A** is the convergence curves of all algorithms; obviously, BBMA has the fastest convergence speed of twelve mentioned algorithms. As can be seen from **Figure 4A**, BBMA has the highest stability, and GWO is the worst. **Figure 5A** shows that, among the fitness values of 30 runs, BBMA is better than other algorithms in most cases, but AMO is three times better than BBMA, SMA is three times better than it, and MA is six times better than it. **Figure 12A** shows the minimum spanning tree for 25 points.

The comparison results of twelve algorithms at 50 points are shown in **Table 1**. It can be seen that the best value, worst value, and mean value of BBMA are the best, but the standard deviation ranks fifth, behind SOA, AMO, GWO, and DE. **Figure 3B** and **Figure 4B** show the convergence curve and analysis of variance results, respectively. By observing the convergence curve, we can clearly see that BBMA has the highest accuracy and the fastest convergence speed. Also, the result of variance analysis shows that BBMA is stable for solving this problem. The fitness values for 30 runs is shown in **Figure 5B**, and it can be seen that BBMA outperforms all other algorithms in 30 runs. **Figure 12B** shows the minimum spanning tree for 50 points.

The comparison of 75 points is shown in **Table 1**. BBMA is better than others in the best value, worst value, and mean value, but its standard deviation is 3.5118 which is worse than the standard deviation of PSO, GA, GOA, GWO, and SOA. Besides, GA has the worst accuracy. By observing **Figure 3C**, it can be noticed that both convergence accuracy and convergence speed are the highest for BBMA. As can be seen from **Figure 4C**, BBMA is still stable. The fitness values of 30 runs and the minimum spanning tree of 75 points can be seen in **Figure 5C** and **Figure 12C**.

The experience results for 100 points are shown in **Table 1**. The performance of BBMA is superior to that of others in the best, worst, and mean value. The best value of BBMA is 69.2455, and the best value of MA is 93.0942. BBMA is 25.83% better than the original algorithm. **Figure 3D** shows that BBMA has the highest accuracy and it still has excellent exploitation ability when other algorithms are stuck in a local optimal value. **Figure 4D** shows that BBMA has high stability. **Figure 5D** and **Figure 12D** show the fitness values for 30 runs and the minimum spanning tree path optimized for 100 points.

It can be seen from **Figure 13A** that BBMA runs the longest at each case, and GA and GWO are the two fastest algorithms. In addition to the running time, by comparing with other eleven algorithms, BBMA has the best performance in low dimensions. In addition, this study statistically tests the proposed algorithm. The Wilcoxon rank-sum non-parametric test results are shown in **Table 2**. BBMA is tested with others at the d = 0.05 significance level. If p values in the table are all less than 0.05, it will prove that BBMA is obviously better than others. Statistically, the experimental results are significant.

Comparison of Algorithms for Medium-Dimensional Cases

In this section, BBMA and other eleven algorithms are tested in six medium-dimensional cases from 150 points, 200 points, 250 points, 300 points, 350 points, and 400 points. **Table 3** records the best, worst, and mean value, standard deviation, and the ranking of the mean value. The bold data indicates that it is the best value of the twelve algorithms. **Figure 6** shows the convergence curves of these six cases, and **Figure 7** shows the ANOVA test results for each case. The fitness values for 30 runs are shown in **Figure 8**. Also, the minimum spanning tree for these cases is listed in



Figure 12E-J, where "ROOT" is the root of the minimum spanning tree. In addition, Figure 13B shows the average running time of the twelve algorithms in different

dimensions. Finally, the Wilcoxon rank-sum nonparametric test results in medium-dimensional cases are shown in **Table 4**.



(D) The ANOVA test for 300 points. (E) The ANOVA test for 350 points. (F) The ANOVA test for 400 points.

 Table 3 displays the experience results of 150 points and 200

 points. Also, the statistical data shown in these tables reflect

 the great difference between different algorithms in

searching ability. We can discover that except standard deviation, the best value, worst value, and mean value of BBMA are all the optimal. Also, the performance of GA is



30 runs for 250 points. (**D**) Fitness values for 30 runs for 300 points. (**E**) Fitness values for 30 runs for 350 points. (**F**) Fitness values for 30 runs for 400 points.

the worst. **Figures 6A,B** are the convergence curves for the two cases, and it can be seen that BBMA has a faster convergence speed and accuracy and strong exploration ability. **Figures 7A,B**

show the analysis of variance results for the two cases, and we can see that the stability of BBMA is at a relatively high level. **Figures 8A,B** are the fitness values in 30 runs for 150 and 200

 TABLE 4 | Wilcoxon rank-sum test results in medium dimensions.

Points	MA	AEFA	PSO	ICA	GA	GOA	GWO	SOA	SMA	DE	AMO
150	1.7344E-06										
200	1.7344E-06										
250	1.7344E-06										
300	1.7344E-06										
350	1.7344E-06										
400	1.7344E-06										

TABLE 5 Experimental results for the two algorithms for 500, 600, 700, 800, 900, and 1,000 points.

Points	Algorithms	Best	Worst	Mean	Std	Rank
500	BBMA	526.7288	576.1991	551.4301	10.9296	1
	MA	671.1059	726.2274	713.1005	13.0341	2
600	BBMA	661.5117	720.9847	687.1937	15.486	1
	MA	827.6303	881.1784	869.5585	11.0172	2
700	BBMA	795.8841	887.1201	826.7429	20.7736	1
	MA	973.2014	1029.001	1014.8361	14.729	2
800	BBMA	920.5137	1003.6668	961.2036	21.599	1
	MA	1150.4318	1184.9458	1172.4426	9.8713	2
900	BBMA	1072.6695	1167.2939	1107.1993	28.7825	1
	MA	1285.7222	1342.1227	1324.583	11.7061	2
1000	BBMA	1167.5382	1344.4605	1248.6469	34.2288	1
	MA	1427.1684	1490.0547	1476.1061	12.4662	2

The optimal values are shown in bold.

points. The MST for the two cases can be found in Figures 12E,F.

Table 3 also shows the comparison results of different algorithms at 250 points and 300 points. BBMA is the best in the best, worst, and mean value, and GA is the worst. However, as for the standard deviation, GWO is the best at 250 and 300 points. Figures 6C,D show the convergence curves in these two cases. The convergence speed and accuracy of BBMA are much superior to others. When other algorithms fall into local optimization, it still has good performance. The results of analysis of variance can be seen in Figures 7C,D, and BBMA has high stability. Figures 8C,D show the curves of the fitness values of 12 algorithms running independently for 30 times in these two cases. The search accuracy of BBMA is much better than that of the other 11 algorithms. Figures 12G,H show the MST at 250 points and 300 points, respectively.

The situation at 350 points and 400 points is shown in **Table 3**. BBMA performs best in the best, worst, and mean value. Compared with the best value of MA, the accuracy of BBMA is improved by 26.88% at 350 points and 24.85% at 400 points. As shown in **Figures 6E,F**, with the growth of dimension, the performance of BBMA is getting better and better. Most algorithms fall into local optimal solution at generation 100, but BBMA always has strong search ability. **Figures 7E,F** show the analysis of variance results in two cases, **Figures 8E,F** show the fitness values of 30 runs, and **Figures 12I,F** show the MST. It can be seen that BBMA has high stability and has better ability to solve spherical MST problems in medium-dimension cases than in low-dimension cases.

TABLE 6 Wilcoxon rank-sum test results in high dimensions.										
Points	500	600	700	800	900	1000				
MA	1.7344E- 06	1.7344E- 06	1.7344E- 06	1.7344E- 06	1.7344E- 06	1.7344E- 06				

In addition, Figure 13B shows that the average running time of BBMA is the longest in the six cases. Compared with other algorithms, MA, DE, and AMO also run longer. Through the abovementioned analysis, we have noticed that BBMA has the outstanding performance in the medium-dimensional cases. The Wilcoxon rank-sum test results are shown in **Table 4**. Similarly, the p values in the table are all less than 0.05, which proves that BBMA algorithm is better than others in medium dimensions.

Comparison of Algorithms for High-Dimensional Cases

In Comparison of Algorithms in Low-Dimensional Cases and Comparison of Algorithms for Medium-Dimensional Cases, BBMA has been compared with other 11 algorithms in low and medium dimensions. BBMA shows very superior performance. Most of the problems encountered in real life are complex and high-dimensional problems, so in this section, BBMA and MA are tested in higher dimensions where n = 500, 600, 700, 800, 900, and 1,000 (see **Table 5**).

Table 5 shows the comparison results of BBMA and MA in six high-dimensional cases and also compares the best, worst, and mean value and standard deviation. The bold data indicate that it is the optimal result of the two. It can be seen that BBMA is superior to its original algorithm in the first three items in each case. The convergence curves of the two algorithms are shown in Figures 9A-F; obviously, the convergence speed and convergence accuracy of BBMA are better, and both exploration and exploitation capabilities have been greatly improved. The results of analysis of variance are shown in Figures 10A-F, and MA is more stable than BBMA. The fitness values of 30 independent operations are shown in Figures 11A-F. Also, Figures 12A-P show the MST of BBMA in different cases, where "ROOT" is the root of the MST, and the minimum spanning tree produced by BBMA is of high quality. Figure 13C is a histogram of the average running time of BBMA and MA, and we find that BBMA runs longer. Finally,







FIGURE 11 | Fitness values for high dimensions. (A) Fitness values for 30 runs for 500 points. (B) Fitness values for 30 runs for 600 points. (C) Fitness values for 30 runs for 700 points. (D) Fitness values for 30 runs for 800 points. (E) Fitness values for 30 runs for 900 points. (F) Fitness values for 30 runs for 1000 points.







Table 6 shows the results of the Wilcoxon rank-sum test in high-dimensional cases. The p values are so small that we can know that BBMA is significantly better than MA.

CONCLUSION AND FUTURE WORK

Mayfly algorithm is a new population-based bioinspired algorithm, which has strong ability to solve continuous problems. It combines the advantages of PSO, FA, and GA and has superior exploration ability, high solution accuracy, and fast convergence. It improves the shortcoming that MA has many initial parameters and the parameters have a large impact on the results. Furthermore, Lévy flight is used for updating the position of the optimal male and excellent female to help the algorithm escape from local optimal solution. In addition, in order to make effective use of the search space, a cross-border punishment mechanism similar to "mirror wall" is used to deal with cross-border individuals. In order to demonstrate the effectiveness of BBMA, the MST problems are solved on a sphere. Compared with MA, AEFA, GA, PSO, ICA, SOA, GOA, GWO, SMA, DE, and AMO in 16 different cases, the test results show that BBMA has superior solving ability, and the higher the dimension is, the more obvious the superiority of BBMA will be. Therefore, BBMA is a good method for large-scale problems in real life. According to the NFL theorem, there is no algorithm that has superior performance for any problem. BBMA has some limitations in solving the spherical MST problems: its running time is relatively long, and its stability needs to be improved. In the future, BBMA will be further applied for solving the spherical MST problems in real life, such as removing noise on the femoral surface and directional location estimators (Kirschstein et al., 2013; Kirschstein et al., 2019). Also, it will be applied to other practical applications, such as logistics center location, path planning, weather forecast, and charging station address selection.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding authors.

AUTHOR CONTRIBUTIONS

TZ: Investigation, experiment, writing-draft; YZ: Supervision, Writing-review and editing. GZ :Experiment, formal analysis; WD: Writing—review and editing. QL:Supervisio.

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