Implementation Work
Search methods
Backpack problem
IA-2024-I

1. Description of the representation scheme used by the implementations employed, and description of the strategy for generating new possible solutions.

The representation scheme used for each bioinspired search method is a list of integers (vector), where each number in the list indicates the objects selected from the total number of available objects. The position of each number in the vector corresponds to the object ID in Excel. In addition, the time taken by the method to find the solutions, the number of iterations it made to reach that solution, the weight and the maximum value obtained are indicated.

The new possible solutions are described as follows:

1.1 AG

Figure 1. Possible solution of GA.

```
Algoritmos genéticos
Tiempo empleado: 36.0811 seg
Iteración la mejor solución: 832
Peso de la mejor solución: 2.442
Valor óptimo: 5168119
Mejor solución: [0, 0, 0, 0, 0, 11, 0, 0, 0, 0, 0, 0, 0, 0, 0]
```

For the solution in **Figure 1,** the list indicates that 11 objects of the 19 available are accommodated from Id 6, resulting in a total weight and value in the backpack of 2.442kg and 5168119 respectively. The time taken is 36.0811sec, with a number of iterations of 832.

1.2 SA

Figure 2. Possible SA solution.

```
Algoritmo de enfriamiento simulado
La mejor solución se alcanzó en la iteración: 32854
Tiempo empleado: 0.1766357421875
Solución óptima: [0, 0, 0, 0, 0, 11, 0, 0, 0, 0, 0, 0, 0, 0, 0]
Valor óptimo: 5168119.0
Peso de la mochila: 2.442 kg
```

In **Figure 2** the list represents that 11 objects of the 19 available are accommodated from Id 6, due to this, a total weight and value in the backpack of 2.442kg and 5168119 respectively are reached. The time used is 0.176sec, with a number of iterations of 32854.

1.3 ACO

Figure 3. Possible ACO solution.

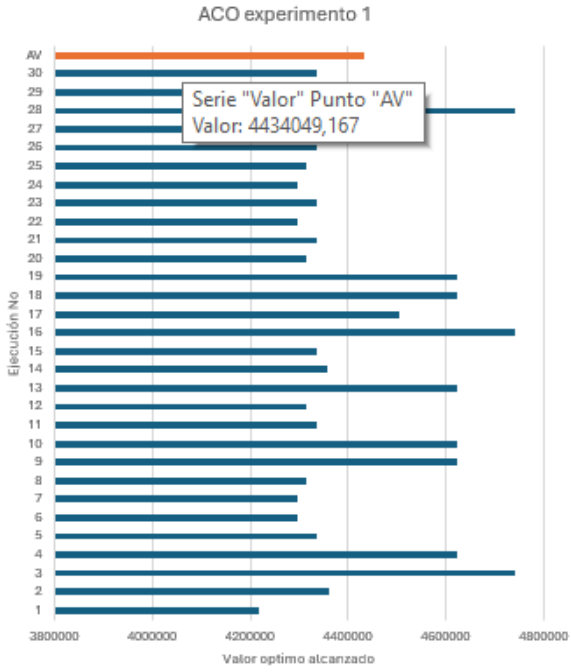
```
Algoritmo de colonias de hormigas
La mejor solución se alcanzó en la iteración número 22.
tiempo de duracion: 5.1860339641571045
Mejor Valor Global: 5168119
Peso Total en gr: 2442
Mejor Solución Global (Cantidad de Ítems seleccionados): [0, 0, 0, 0, 0, 11, 0, 0, 0, 0, 0, 0, 0, 0, 0]
```

In **Figure 3,** the list indicates that 11 objects of the 19 available are accommodated from Id 6, therefore, a total weight and value in the backpack of 2442g and 5168119 respectively are reached. The time taken is 5.18 seconds, with a number of iterations of 22.

2. Graphs and tables summarizing the results obtained. For each method, the results obtained with a minimum of three different parameter configurations are shown, including a final configuration with the best combination of parameters found.

2.1 ACO

Analysis of ACO performance (experiment 1)



Convergencia ACO (experimento 1)

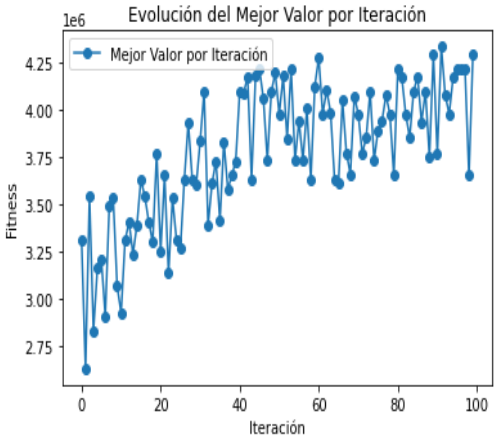


Tabla 1. Resumen de las 30 ejecuciones de ACO (experimento 1)

	Valores
Mínimo	4216596
Máximo	4741006
Promedio	4434049,17
Varianza de la muestra	2,6702E+10
Tiempo Promedio	0,5796301
Iteración Promedio	70,4

Parámetros de ACO (experimento 1)

peso_maximo = 2450
num_hormigas = 20
num_iteraciones = 100
evaporacion = 0.1
feromona_inicial = 0.9
alpha=0.3
beta =1

In the ACO performance graphs (experiment 1) it is reflected that, for a number of 30 executions, the optimal values reached are greater than 3800000 and less than 4800000. At no time is it possible to see that the values per iteration converge at the same point, because there is a wide variation in the values.

In **Table 1** the difference between the minimum and maximum value is not evident, despite this, the variance is very high, so the dispersion around the mean is also high.

Furthermore, the solutions tend to converge in a number of 70.4 iterations, which is very low, so the algorithm reaches the solution very quickly.

Analysis of ACO performance (experiment 2)

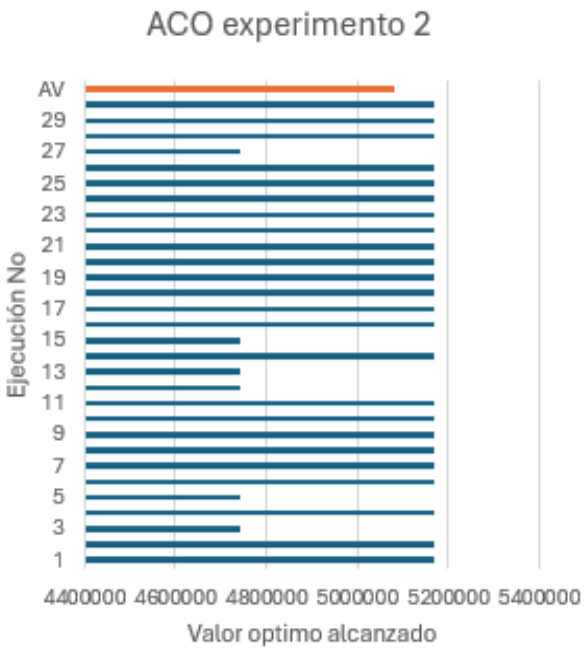
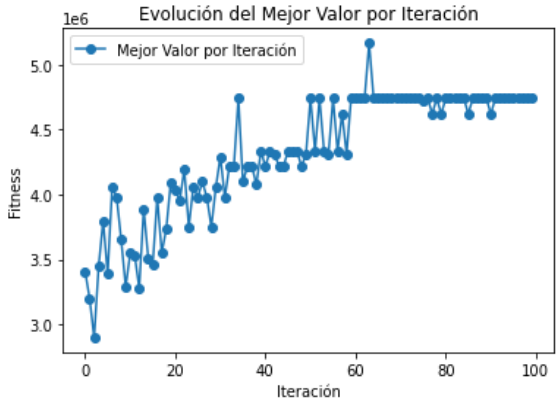


Tabla 2. Resumen de las 30 ejecuciones de ACO (experimento 2)

	Valores
Mínimo	4741006
Máximo	5168119
Promedio	5082696,4
Varianza de la muestra	3,0195E+10
Tiempo Promedio	0,63036802
Iteración Promedio	73,833333

Convergencia ACO (experimento 2)



Parámetros de ACO (experimento 2)

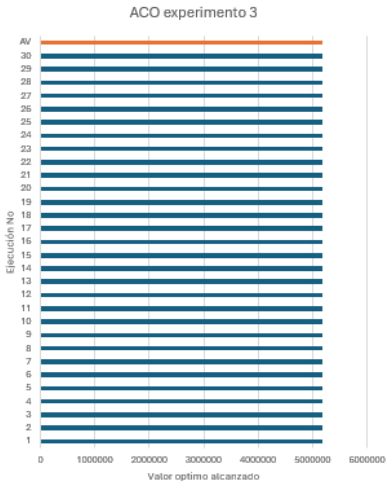
peso_maximo = 2450
num_hormigas = 20
num_iteraciones = 100
evaporacion = 0.1
feromona_inicial =0.3
alpha=0.5
beta =1

In the ACO performance graphs (experiment 2) it is evident that, for most of the executions, the optimal value reached is close to 5200000. It is also observed that

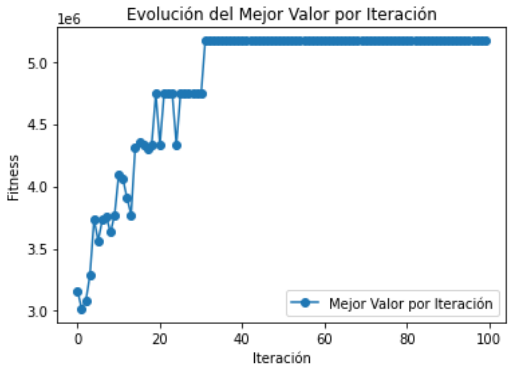
the values begin to converge from iteration 60, but it can be seen that the convergence is towards a local maximum, given that there is an iteration that achieves a better value.

In **Table 2,** the variance increases compared to the previous experiment, the average increases and a better solution is achieved. Also, an increase in the iterations in which the algorithm converges is evident.

Analysis of ACO performance (experiment 3)



Convergencia ACO (experimento 3)



Parámetros de ACO (experimento 3)

peso_maximo = 2450
num_hormigas = 20
num_iteraciones = 100
evaporacion = 0.1
feromona_inicial =0.3
alpha=1
beta =0.5

Tabla 3. Resumen de las 30 ejecuciones de ACO (experimento 3)

	Valores
Mínimo	5168119
Máximo	5168119
Promedio	5168119
Varianza de la muestra	0
Tiempo promedio	0,7625345
Iteración promedio	25,5666667

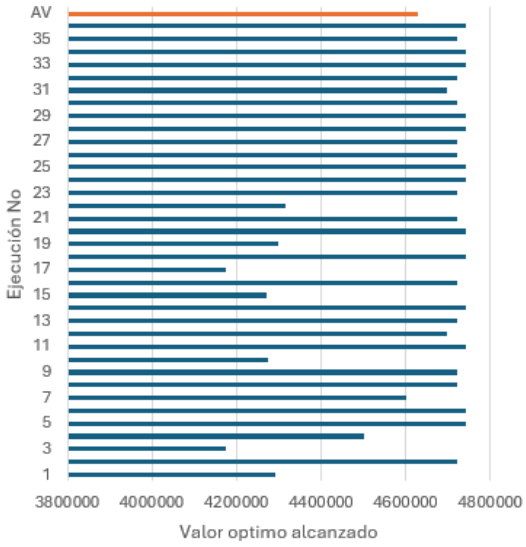
In the ACO performance graphs (experiment 3), all executions approach a value of 5200000 and from iteration 30 the convergence of these values is clearly noticeable.

In **Table 3** the value of the variance is zero, which means that:

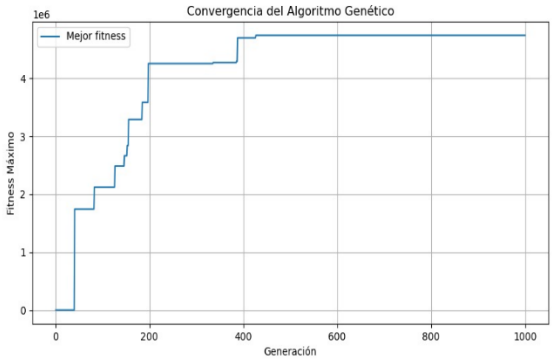
- In the 30 executions that the algorithm carried out, the same solution was always reached.
- The highest possible optimal value was obtained (5168119).
- The number of iterations is smaller compared to the other two experiments.

2.2 AG

Analysis of AG performance (experiment 1)



Convergencia AG (experimento 1)



Parámetros de AG (experimento 1)

tam_poblacion=100
num_generaciones=1000
prob_cruce = 0.8
prob_mutacion=0.1
tam_elite = 5

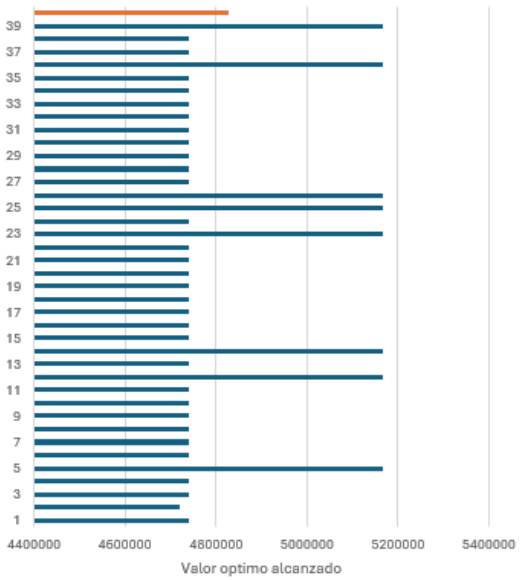
Tabla 4. Resumen de las 30 ejecuciones de AG (experimento 1)

	Valores
Mínimo	4173217
Máximo	4741006
Promedio	4626783,639
Varianza de la muestra	36556897202
Tiempo Promedio	1,337390065
Iteración Promedio	577,94444

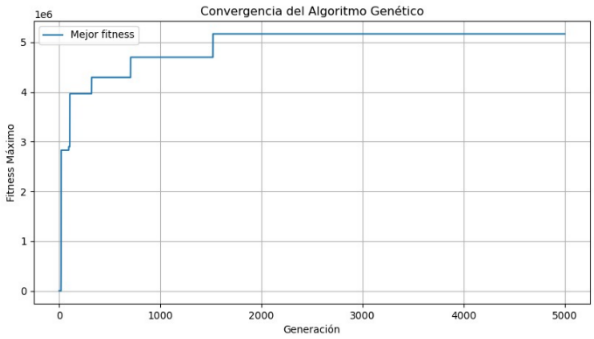
In the performance graphs of AG (experiment 1) it is evident that, of the 30 executions, the majority are above 4600000, which indicates that the solutions provided by the algorithm are reliable.

In **Table 4,** it can be seen that the variance is very high, so the values in the graph are quite dispersed. Each time the algorithm is executed, different optimal values are obtained, and the method tends to converge around 577 iterations, with an approximate time of 1.35 seconds.

Analysis of AG performance (experiment 2)



Convergencia AG (experimento 2)



Parámetros de AG (experimento 2)

tam_poblacion=100
num_generaciones=5000
prob_cruce = 0.8
prob_mutacion=0.08
tam_elite = 3

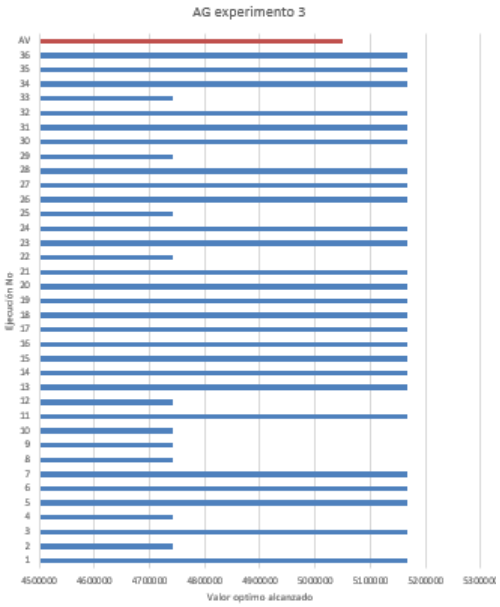
Tabla 5. Resumen de las 30 ejecuciones de AG (experimento 2)

	Valores
Mínimo	4719648
Máximo	5168119
Promedio	4828071,282
Varianza de la muestra	30637529266
Tiempo Promedio	6,34283399
Iteración Promedio	1849,538462

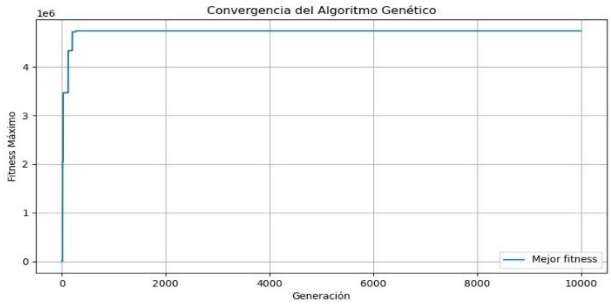
By changing the number of generations, mutation rate and elite size in GA (Experiment 2), the value of a part of the runs is below 4,800,000 and the other part is above 5,000,000. This indicates that better solutions can still be obtained.

In **Table 5** , the average iterations in which the method converges increase significantly, it is observed that the maximum optimal value is 5168119, which is the maximum value that was obtained when solving the backpack problem.

Analysis of AG performance (experiment 3)



Convergencia AG (experimento 3)



Parámetros de AG (experimento 3)

tam_poblacion=1000
num_generaciones=10000
prob_cruce = 0.8
prob_mutacion=0.1
tam_elite = 3

Tabla 6. Resumen de las 30 ejecuciones de AG (experimento 3)

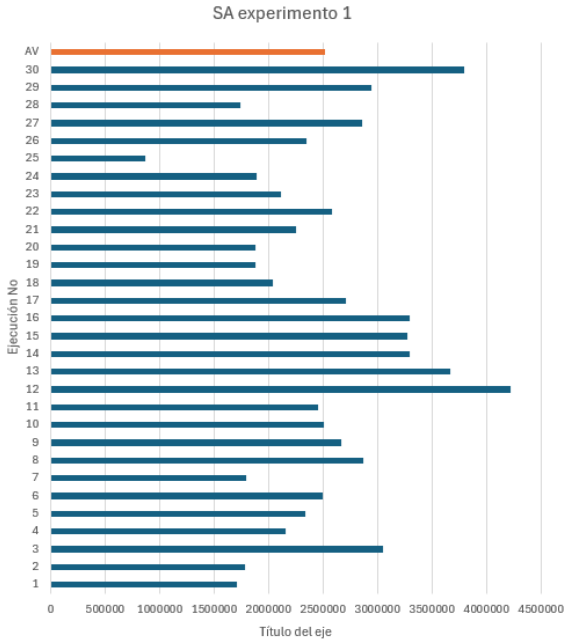
	Valores
Mínimo	4741006
Máximo	5168119
Promedio	5049476,5
Varianza de la muestra	37643360190
Tiempo promedio	88,36445292
Iteración promedio	2230,5

By changing the population size, the number of generations and the elite mutation rate in the GA (experiment 3), a notable improvement is achieved when performing the executions, it is obtained that the majority of the optimal values are above 5000000, which indicates a greater reliability in the solution.

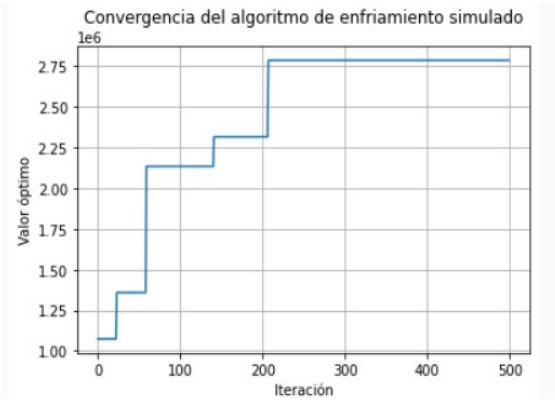
In **Table 6,** it can be observed that the variance increases compared to the previous two experiments, however, a better average between the values is noted. The average iterations increase, although not as significantly as the average time, which goes from 6 seconds to 88 seconds compared to the GA (experiment 2).

2.3 SA

SA performance analysis (experiment 1)



Convergencia SA (experimento 1)



Parámetros de SA (experimento 1)

Temperatura inicial = 100
Tasa de enfriamiento = 0.99
Temperatura final = 500

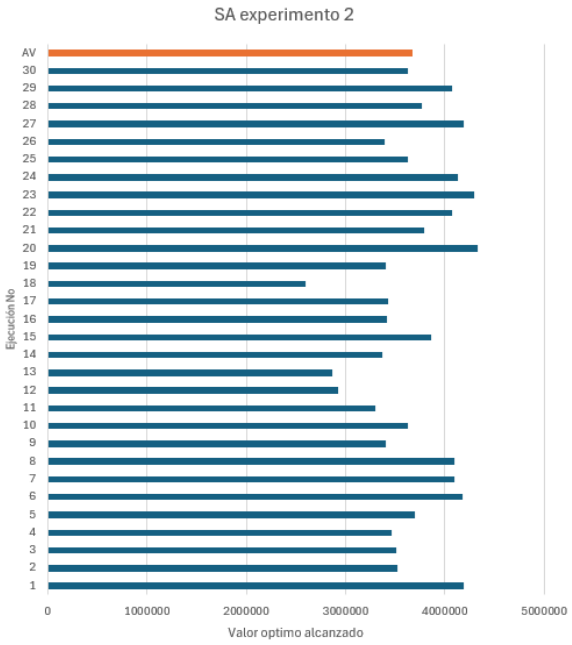
Tabla 7. Resumen de las 30 ejecuciones de SA (experimento 1)

	Valores
Mínimo	870353
Máximo	4216596
promedio	2515396,9
Varianza de la muestra	5,27378E+11
Tiempo promedio	0,010
Iteración promedio	319,867

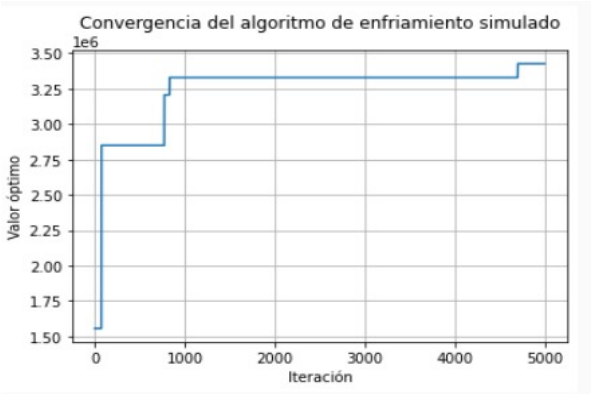
With the graphs of the SA performance (experiment 1) it can be observed that when performing the 30 executions very few similar solutions are obtained, therefore, it is not reliable to choose an optimal solution to the problem, in addition only one solution obtained a value higher than 4000000.

When analyzing **table 7** , it is noted that the variance is very high, which indicates that the values are very dispersed around the mean which is 2515396.9, so the minimum is 870353 and the maximum is 4216596. The solutions tend to converge in iteration 319 in a very short time.

SA performance analysis (experiment 2)



Convergencia SA (experimento 2)



Parámetros de SA (experimento 2)

Temperatura inicial = 100
Tasa de enfriamiento = 0.99
Temperatura final = 5000

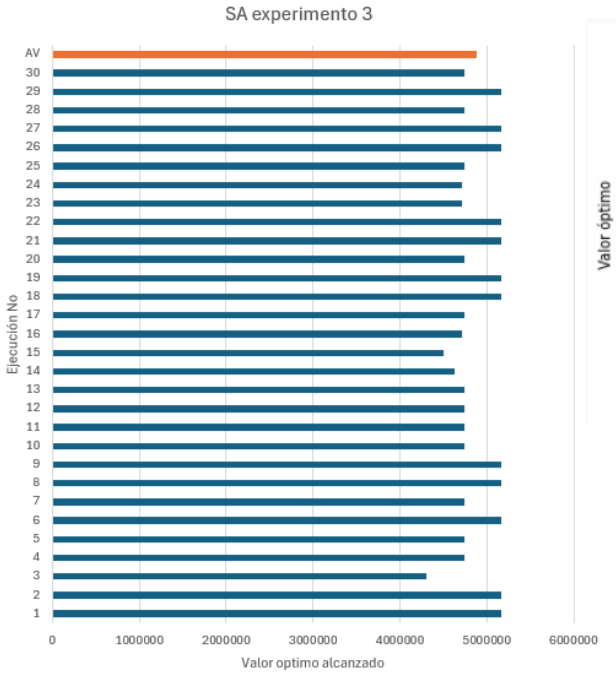
Tabla 8 Resumen de las 30 ejecuciones de SA (experimento 2)

	Valores
Mínimo	2593112
Máximo	4335251
Promedio	3676207,23
Varianza de la muestra	1,94363E+11
Tiempo promedio	0,040811086
Iteración promedio	3665,3

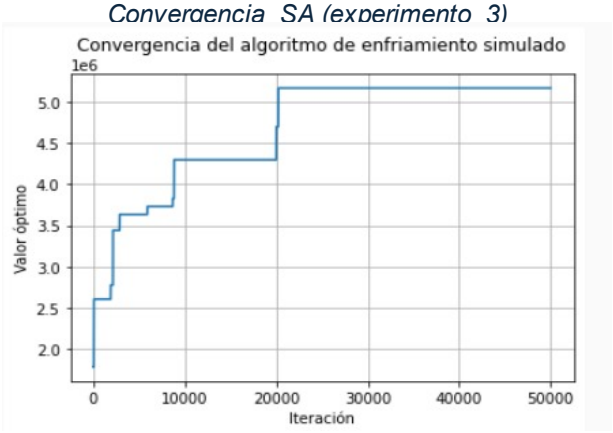
By changing the final temperature in the SA (experiment 2), it is noted how the solutions in each iteration provide a greater value than in experiment 1, that is, a greater number of solutions above 4000000 begin to be found. Consequently, if the final temperature is increased, the behavior will be better.

In **Table 8,** the variance is reduced somewhat, but it is still very high. The average number of iterations in which an optimal value is reached increases, and therefore the execution time also increases.

SA performance analysis (experiment 3)



Convergencia SA (experimento 3)



Parámetros de SA (experimento 3)

Temperatura inicial = 100
Tasa de enfriamiento = 0.99
Temperatura final = 50000

Tabla 9 Resumen de las 30 ejecuciones de SA (experimento 3)

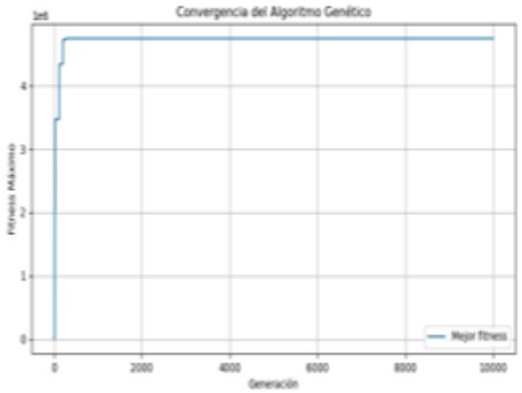
	Valores
Mínimo	4296698
Máximo	5168119
Promedio	4883039,633
Varianza de la muestra	63899059440
Tiempo promedio	0,325
Iteración promedio	30823,7

By increasing the final temperature of the SA (experiment 3) to 50000, an excellent improvement in the solutions is perceived, therefore, in each execution solutions between four and five million are achieved, thus observing a better similarity between each solution, which makes the optimal values achieved much more reliable.

In **Table 9** the change in variance is not significant, therefore, there is not such a noticeable difference compared to the minimum and maximum of the other two experiments.

3. The best experiment of each bioinspired search method.

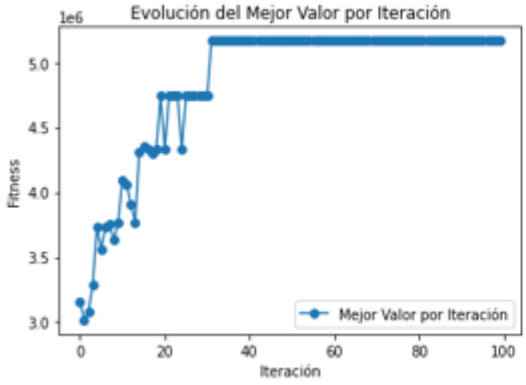
3.1 Best AG result



	Valores
Mínimo	4741006
Máximo	5168119
Promedio	5049476,5
Varianza de la muestra	37643360190
Tiempo promedio	88,36445292
Iteración promedio	2230,5

Figure 4. Representation of the best AG result.

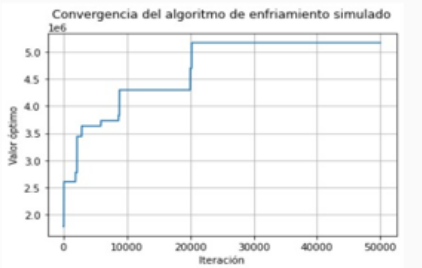
3.2 Best ACO result



	Valores
Mínimo	5168119
Máximo	5168119
Promedio	5168119
Varianza de la muestra	0
Tiempo promedio	0,7625345
Iteración promedio	25,5666667

Figure 5. Best ACO result.

3.3 Best SA result



	Valores
Mínimo	4296698
Máximo	5168119
Promedio	4883039,633
Varianza de la muestra	63899059440
Tiempo promedio	0,325
Iteración promedio	30823,7

Figure 6. Best SA result.

4. Comparison of methods with each other, in terms of the average time required, the number of iterations to converge, the best solution found, and the variance.

4.1 Comparison of the 3 methods with box plots

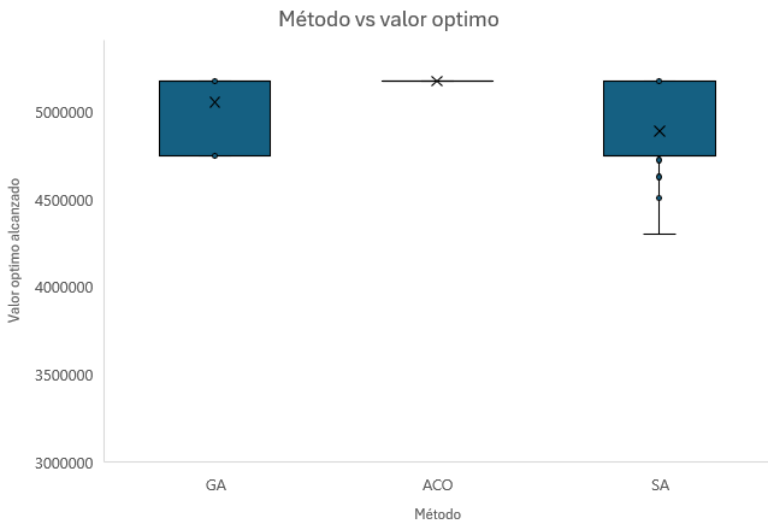


Figure 7. Box plot.

The box plot shows that the distribution is similar for AG and SA, but this distribution is not normal. In addition, it is evident that the data are more dispersed in the SA method, although in the case of the AG method the mean is above the SA. The ACO method does not show any variance and is therefore the best solution.

4.2 Comparison of the 3 methods with line graphs

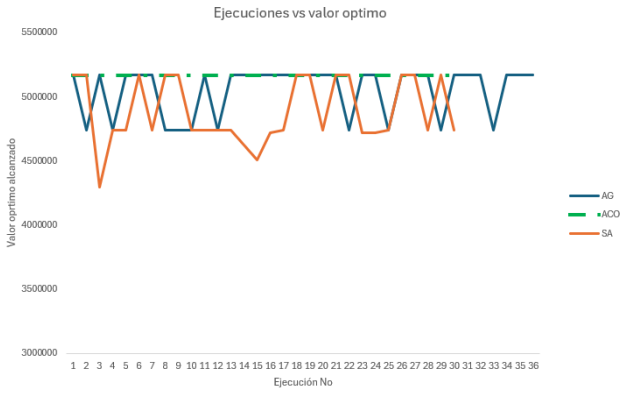


Figure 8. Line graphs.

In **Figure 8** it can be seen that the solutions of the 3 methods revolve around the same optimal values, however, the SA method obtains some solutions with smaller optimal values than the rest, because it has a greater variance.

4. 3 Comparison of the 3 methods with respect to time with bar chart

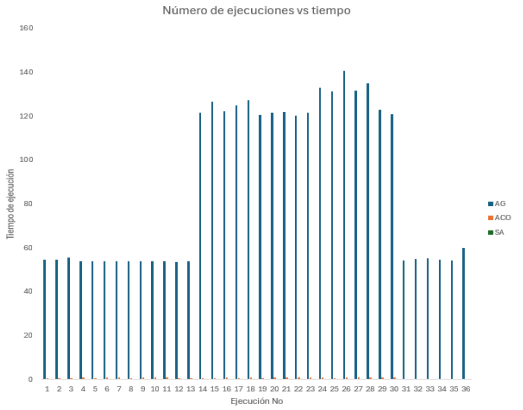


Figura 9. Número de ejecuciones vs tiempo de los 3 métodos.

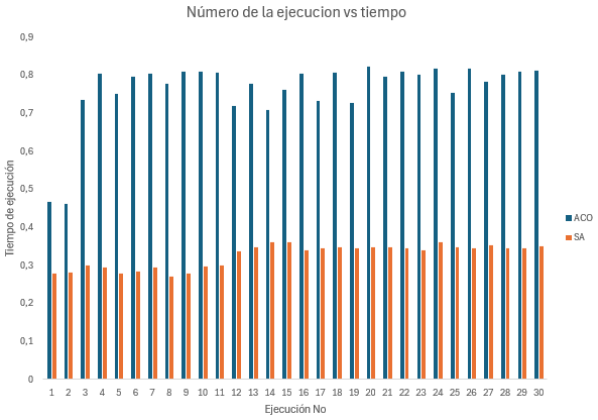


Figura 10. Número de ejecuciones vs tiempo del método ACO y SA.

Figure **9** shows that the time of the AG method is much longer than the ACO and SA methods respectively, therefore, these last two methods cannot be seen in the graph.

In **Figure 10,** when comparing the ACO and SA methods, it was found that the SA method presents the shortest time, although this difference is not as significant with respect to the ACO method because the difference is around 0.5 sec.

4.4 Comparison of the 3 methods regarding the number of iterations with bar chart

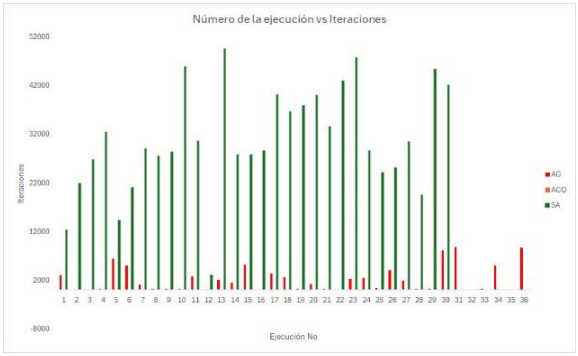


Figura 11. Número de ejecuciones vs iteraciones de los 3 métodos.

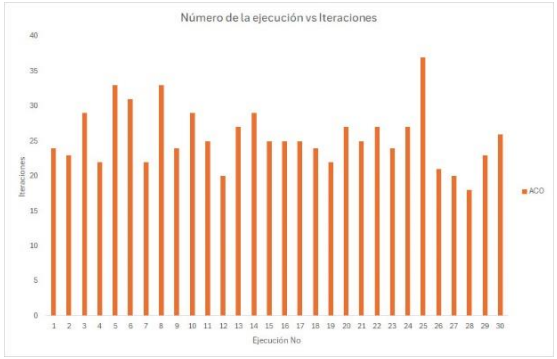


Figura 12. Número de ejecuciones vs iteraciones del método ACO.

Figure **11** compares the number of executions versus the number of iterations between the three methods. It can be seen that the SA method has a higher number of iterations than the other two methods, so the iterations of the ACO method cannot be visualized.

Due to the scale of the graph, a second graph is required to show the behavior of the ACO method (see **figure 12**). This figure shows that the optimal solution is reached with a significantly lower number of iterations than in the other methods.

5. Results

- When analyzing the 3 methods, it is found that the ant colony algorithm (ACO) presents a better performance, since when analyzing the solutions of the 30 executions, it tends to generate the same solution, due to the fact that the value of its variance is zero, compared to the SA and AG methods that have a very high variance.
- The ACO method converges in a smaller number of iterations, and although it is not the method that delivers a solution in the shortest time, the time it takes is still very short.
- The simulated cooling (SA) method delivers an optimal solution in less time than the ACO and AG methods, and it is also evident that it processes a greater number of iterations in a shorter time. However, it is the one with the highest variance of the 3 methods. However, it was observed that as the final temperature increases, the variance decreases.
- The AG method is the one that takes the longest to deliver a possible solution.