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Hybrid metaheuristic algorithm (SAGAC) used in optimization of vacuum cooling treatment of postharvest broccoli

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Abstract

This research aims to analyze the application of the hybrid metaheuristic algorithm SAGAC, which is composed of the Simulated Annealing (SA) and Genetic Algorithm (GA) techniques with the inclusion of a convergence acceleration (AC) mechanism. SAGAC was used to optimize the postharvest broccoli vacuum cooling process. Another concern included in the algorithm is population diversity, and, for this situation, a high mutation rate (40%) and a low elitism rate (10%) were used. The objective of maintaining population diversity is to avoid premature and undue convergence of the results curve. The SAGAC algorithm's performance was compared with another type of approach in optimizing this process, which used the Response Surface (RSM) methodology combined with the Genetic Algorithm (GA), here, called RSMGA in this present study. The results obtained showed that the SAGAC algorithm obtained better results concerning RSMGA in optimizing this process.

Key-words

Algorithms, Optimization, SAGAC, Metaheurísticas.

1. Introduction

According to Santana et al. (2018), broccoli is a food rich in vitamin C, fiber, and multiple other nutrients with potent anti-cancer properties. In the world, China and India are the largest producers of this vegetable, and together they produce more than 75% of all global production. According to Santana et al. (2018), broccoli has a short shelf life at room temperature. Hence, the search for efficient ways to preserve this type of food's validity and nutritional properties becomes essential.

In Alibas & Koksal (2014), Carvalho & Clemente (2004), and Corcuff et al. (1996), there are several techniques to improve the shelf life of food, such as drying, freezing, and modification in most packaging. In McDonalds et al. (2002), vacuum cooling is achieved by rapidly removing heat from the product by evaporating water from the surface and pores. For Zhang & Sun (2006), vacuum cooling has been reported as a highly efficient method to extend the shelf life and improve biological safety. According to Funes et al. (2015), there has been an increase in the development of competitive and electronic approaches to agricultural tasks in recent decades, such as harvesting, sowing, growth monitoring, soil analysis, and chemical treatments. Such approaches, an example of the mentioned approaches, use hybrid algorithms to optimize processes, especially to reduce the search space to find the ideal conditions and, thus, reduce the computational time (CHAVES et al., 2007). Abbasi & Mahlooji (2012) applied the simulated annealing (SA) technique and the response surface methodology (RSM) to explores the relationships between several explanatory variables and one or more response variables.

This research aimed to investigate the SAGAC hybrid algorithm's performance compared to the RSMGA approach by Santana et al. (2018) to optimize the postharvest broccoli vacuum cooling process. The main benefit of the proposed approach is the increase in the producers' profit due to the reduction obtained with the implementation of the SAGAC algorithm.

2. Materials and Methods

2.1. Vacuum cooling treatments

According to Santana et al. (2018), the vacuum cooling treatment was implemented by a self-developed vacuum cooler with a water-spraying unit connected with the water pipe and vacuum chamber. The water-spraying volume can be controlled in this system. The equipment was developed in chromed steel, with an internal volume of $1m^{3,}$ and it was made in the Department of Food Science and Nutrition, School of Biosystems Engineering and Food Science, Zhejiang University, city of Hangzhou, Zhejiang Province, China. In this study, the pressure in the vacuum chamber (200, 400, and 600 Pa), the water-spraying volumes (3%, 4%, and6%), and the processing time (20, 30, and 40 min) were varied to investigate their synthetic effects on the weight loss(W_{loss}) of broccoli during the vacuum cooling process (Alibas & Koksal, 2014; Deng et al., 2011; Zhang & Sun, 2006).The processing time is the cooling time required to reach the experimental design pressure conditions within the refrigerator.

2.2. Modeling process

An experimental design was used for the organization of the assay of this experiment. After the experiments' execution (duplicate), the minimum square method was applied to the experimental data to obtain the model (Santana et al., 2018). Was considered the following factors: pressure, P (x_1), broccoli weight, W (x_2), water volume, V (x_3), and processing time, t

(x_4); as well as the following responses: loss of weight (y_1), W_{loss}, and end temperature(y_2), T_{end}. Because of the effect of inconsistencies caused during the computations, it was necessary to normalize the variables $x_i \in [-1, 1]$.
The mathematical formulation of this problem is summarized in the following equations:

Weight loss is calculated by equation (1)

$$W_{loss} = 0.9619 - 0.2756x_1 - 0.9195x_2 + 0.2786x_1^2 + 0.4936x_2^2 - 0.6914x_4^2 - 0.7725x_1x_3 + 0.5807x_1x_2x_3x_4$$

The end temperature is calculated by equation (2)

$$T_{end} = 8.9690 + 2.0083x_1 + 1.8834x_2 + 0.7714x_3 - 0.8750x_1^2 - 1.1000x_2^2 - 1.2500x_4^2 + 1.8000x_1x_2x_3x_4$$

Domain of variables:

$x_1 \in [200 ; 600]$; $x_2 \in [200 ;500]$; $x_3 \in [0.03 ;0.06]$; $x_4 \in [20 ;40]$

The objective function is calculated by equation (3)

$$Minimize: OF = \alpha W_{loss}(x_1, x_2, x_3, x_4) + \beta T_{end}(x_1, x_2, x_3, x_4)$$

where α=0.9 and β=0.1

Subject to:

$$o.o < T_{end} \leq 2.0$$
$$W_{loss} \geq 0$$
$$x_i \in [-1.0,1.0]$$
$$\alpha + \beta = 1.0$$

where α and β are the weight of W_{loss} and T_{end}, respectively.

The normalized values of variables are calculated by equation (4)

$$x_1 = \frac{P_j - 400}{200}$$
$$x_2 = \frac{W_j - 350}{150}$$
$$x_3 = \frac{V_j - 4.5}{1.5}$$
$$x_4 = \frac{t_j - 30}{10}$$

In China, the typical price for broccoli is 4.0 US$/ kg, and for kWhis 8 cents. These values were used to calculate Eq.'s total profit (5) (SANTANA et al., 2018).

(5)

$$Profit(\%) = (100 - W_{loss}) - 100 * \left(\frac{4.8 * 10^{-4} * t(min)}{4.00}\right)$$

The success of any business is related to maximizing profits. In this case study, it is related to the minimization of W_{loss}. Then, if minimum W_{loss} is found, the maximum profit will be found as well.

3. The hybrid metaheuristic algorithm (SAGAC)

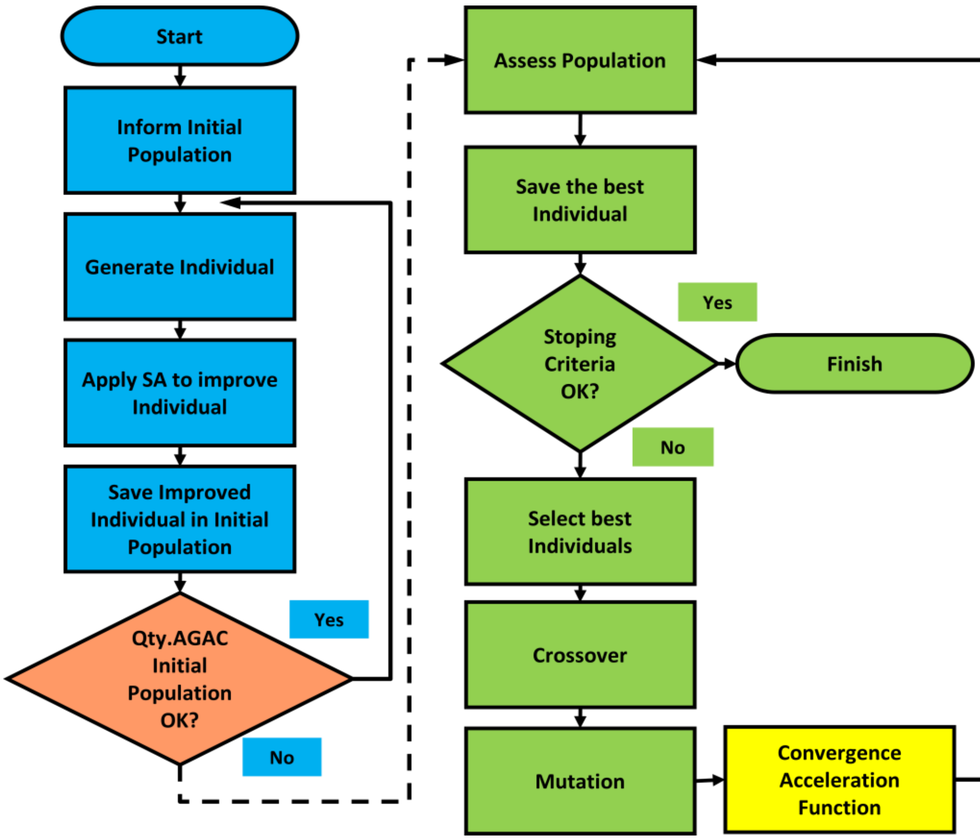
Two algorithms form the algorithm: the Simulated Annealing (SA) and the Genetic Algorithm (AG) with the inclusion of a mechanism (function) that promotes an acceleration in the convergence (AGAC) of the obtained results.

The SA algorithm acts on the generation of individuals who make up the modified genetic algorithm's initial population (AGAC). With the use of the SA algorithm, it is possible to have the composition of a good quality initial population, that is, pre-optimized individuals.

The routine behavior of the AGAC algorithm promotes Convergence Acceleration in which, after crossing, there is an assessment of the individuals (Sons) generated and a check for quality improvement concerning the individuals of the elite group of the population. If such development does not occur, the individual (s) of the child(ren) is(are) discarded, the individual (parent) of the worst quality is exchanged for another individual in the elite group who is closest and is better than the individual (Father) who was changed.

After the individual's change (Father), a new crossing occurs for the missing child's generation (s). This sequence of steps will be repeated until both children meet the criteria for improvement or the stipulated number of attempts is reached. Figure 1 shows the flowchart of the SAGAC hybrid algorithm.

Figure 1 - Scheme of the hybrid SAGAC algorithm.



With each cycle of processing of the Simulated Annealing (SA) algorithm, the best result (individual) is stored to compose the initial population used by the modified Genetic Algorithm with convergence acceleration mechanism (AGAC).

Figure 2 shows the original scheme of a Genetic Algorithm, and, in sequence, Figure 3 shows the Genetic Algorithm with the inclusion of the convergence acceleration mechanism.

Figure 2–Scheme of a classic Generic Algorithm (adapted from Linden, 2008).

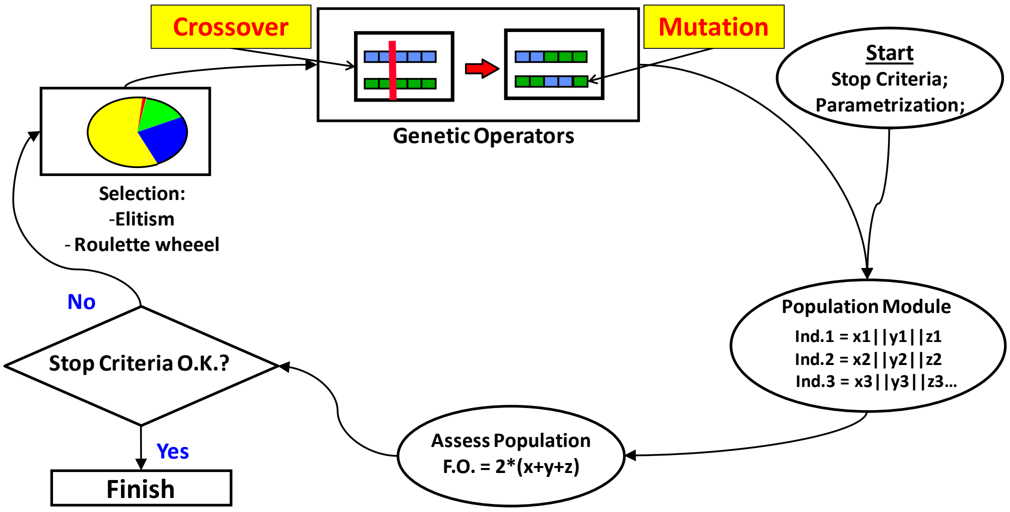
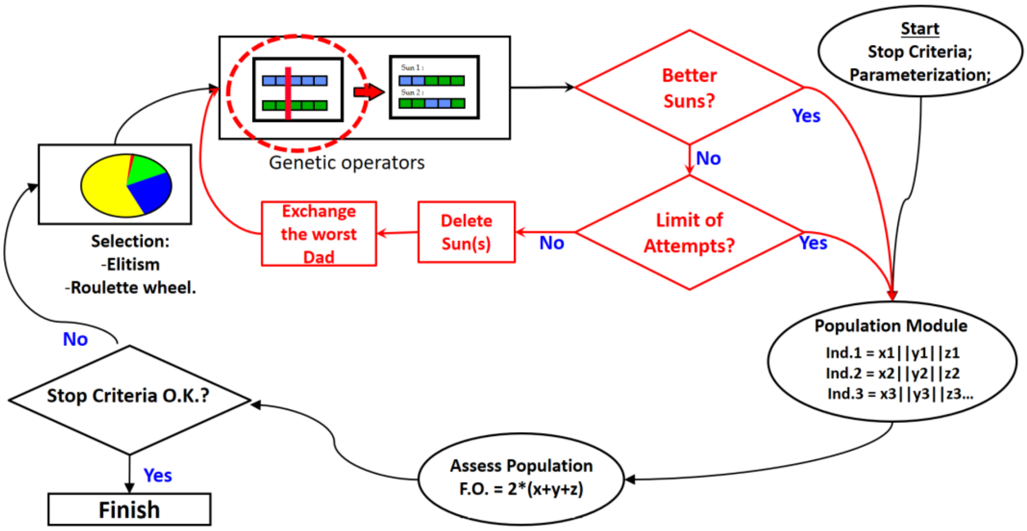


Figure 3–Scheme of a Genetic Algorithm with convergence acceleration mechanism.



Figures 2 and 3 show the change in the Genetic Algorithm using the convergence acceleration mechanism. This mechanism increases the probability of a continuous individuals' evolution over the generations. In each generation of offspring, the algorithm checks whether they have the minimum qualifications to be part of the elite and, if this does not occur, there is a disposal of these offsprings and the generation of others, after changing one of the parents with the worst evaluation.

3.1.Setup Parameters of SAGAC

In SAGAC, the variables that influence the algorithm's behavior are its processing parameters (SOUZA et al. 2017, SANTANA et al. 2011, MITCHEL 1997, KIRKPATRICK et al. 1983).

Parameters of SA

1º. Initial Temperature = 100;

It is the number of cycles that will be processed in an algorithm repetition loop;

2º. TDS = 1;
The Temperature Decay Scheme - defines how the temperature is decreased and the number of iterations performed for each temperature.
- the Temperature Decay Function is represented in equation (6):

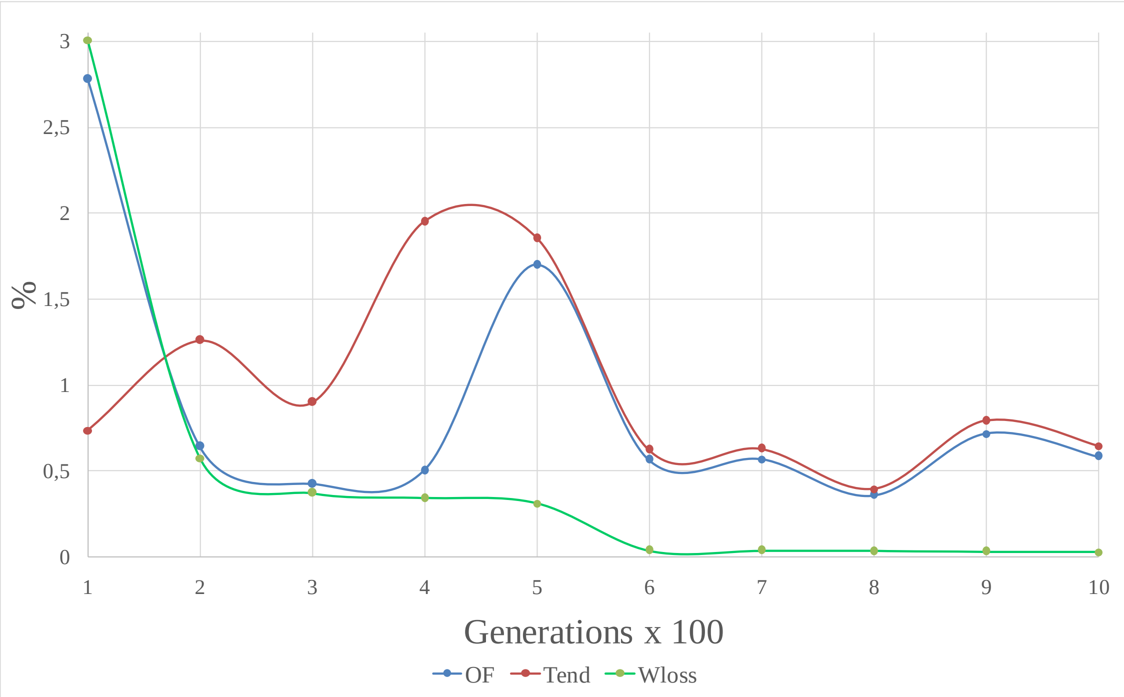
$$Temp_{i+1} = Temp_i - 1 \tag{6}$$

- Number of Iterations at each Temperature = 1
Parameters of AGAC
1º. Population size = 100;
2º. Generations Qty. = 1000;
3º. Elitism = 10%;
4º. Mutation = 40%;
and, for the case of the Convergence Acceleration Genetic Algorithm (AGAC)
5º. Qty of attempts to generate children in the elite = 1.

4. Results and discussion

Figure 4 shows the evolution curves of the values of the factors W_{loss}, Tend, and the value of the Objective Function (OF) of the best individuals in each generation during the 1000 generations processed by the SAGAC algorithm.

Figure 4–Behavior of Wloss, Tend, and Objective Function (OF) factors in optimizingbroccoli's vacuum cooling process.



It is noted in Figure 4 that the T_{end} and OF factors present an oscillating behavior and different from the W_{loss} factor, which presents a negative convergence, which means a decrease in the weight loss of the product. The increase in profit is inversely related to the decrease in the W_{loss} factor.
Next, in Figure 5, the "Profit" convergence curve is shown.

Figure 5–Convergence curve of the "Profit" value obtained by minimizing the factor W_{loss}.

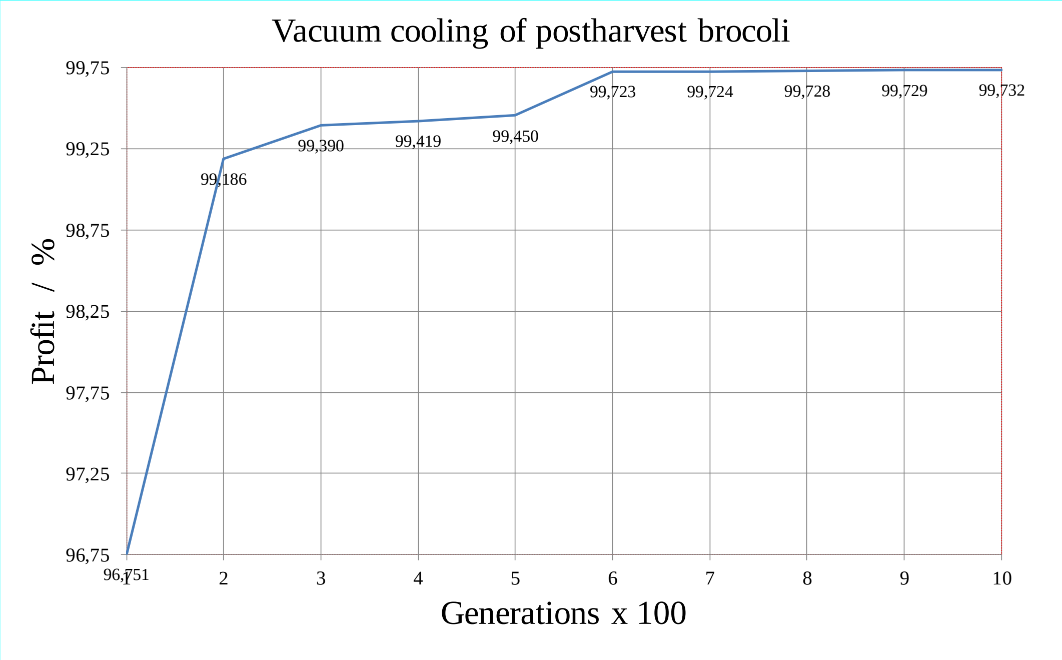


Figure 5 indicates that after 600 generations processed by SAGAC, there is a stabilization of the curve convergence, with small gains.

Table 1 compares the results obtained by the RSMGA and SAGAC algorithms in optimizing vacuum cooling treatment of postharvest broccoli.

Table 1–Comparison of the RSMGA and SAGAC algorithms' results to optimizethe vacuum cooling of broccoli.

Algorithm	X1	X2	X3	X4	W_{loss}	T_{end}	OF	Profit
RSMGA	200,00	273,5 to 278,0	0,03	40,00	0.34 ± 0.01%	2.00 ± 0.00%	0,502327	99.66 ± 0.01%
SAGAC	318,92	230,7	0,03	39,75	0,03	0,65	0,583125	99,73

With the data presented in Table 1, we can see that the SAGAC algorithm obtained the best results concerning the W_{loss} and Profit values. After all, this is the objective of this optimization process, that is, to minimize product weight loss and consequently maximize profit.

5. Conclusions and future work

A hybrid metaheuristic algorithm was proposed to obtain better results in optimizing the vacuum cooling process of broccoli after harvest, coming from the union of the Simulated Annealing (SA) algorithms and the Genetic Algorithm with a convergence acceleration mechanism. (AGAC) which was named SAGAC. In the proposed approach, SA has the function of providing the initial population of the AGAC with individuals of better quality than individuals generated at random. This strategy works as a pre-optimization of the process. Upon receiving this initial pre-optimized population, AGAC raises the quality of these individuals to a higher level.

The results obtained show a better performance of the SAGAC, mainly when we refer to minimizing the product's weight loss (broccoli) and the maximization of the profit.

The SAGAC algorithm showed its potential in optimizing the vacuum cooling process of broccoli after harvesting. A study of its processing parameters remains a suggestion for future work as a form of investigation to improve performance. Additionally, the SAGAC algorithm could be implemented to optimize other actual processes in future works.

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