Particle swarm optimization for designing ideotypes for sustainable production systems

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Abstract

Agricultural systems have to adapt, in a changing climatic context, to face the growing social demand in terms of organoleptic, nutritional and environmental quality of food products. Thus, a crucial question for the future is how to manage fruit quality by finding the best combinations of genetic resources and cultural practices adapted to, and respectful of specific environments. This question was addressed using a particle swarm optimization and a process-based model. The obtained results show the interest of such as approach.

Key words

Optimization, Crop models, Ideotypes, Peach.

1 Introduction

The Fruit is a complex system which is the result of many highly interacting physiological processes that are controlled by many genes whose intensity varies with the environment and cropping practices. The crucial question is how to manage fruit quality by finding the best combinations of genetic resources and cultural practices adapted to, and respectful of specific environments.
Several works have focused to use ecophysiological process-based simulation models that can help in deconvoluting genotype by environment interactions for complex traits [7], and design new ideotypes adapted to target environments [6].
In recent years, modern heuristic optimization techniques, e.g. genetic and particle swarm optimization algorithms have aroused great interest among the scientific community in the agronomy field [4, 6]. In this context, the objective of this work is to illustrate how an ecophysiological process-based simulation model could be used to design ideotypes and thus propose innovative production systems, by applying a heuristic optimization technique: particle swarm optimization (PSO). In the application examined here, i.e., the peach-brown rot system, the challenge is to exhibit peach ideotypes that satisfy the requirement of high quality and low sensitivity to brown rot in a given environment. This sensitivity is strongly related to the skin cracks density.
We take advantage of the process-based model, the "Virtual Fruit" [2], to formulate proper multi-objective optimization problem with respect to fruit physiological processes. The particle swarm optimization algorithm [3], is applied to solve this multi-objective problem based on the "Virtual Fruit".

2 Materials and methods

The "Virtual peach Fruit" is a process-based model which simulates seasonal changes in several peach fruit quality traits during the final growth stage. It takes into account the effect of some climatic factors (radiation, air temperature and humidity), some cultural practices (irrigation, pruning, thinning) and the genotype [5]. The outputs of the "Virtual peach Fruit" considered in this work are three fruit traits: fruit fresh masse, sugar concentration and skin density of cracks. An optimization problem with conflict objectives, maximization of the fruit fresh mass and the sugar concentration and minimization of the crack density, is formulated with respect to constraints. The objective functions are not explicit; their values are given by the "Virtual Fruit" numerical model. The decision variables are the six genetic parameters with significant impact on our three criteria, and the constraints are the domain variations of these continuous variables. To solve this multi-objective problem, we first transform it to a single objective problem by the weighted sum approach or the bounded objective function method. The standard particle swarm optimization algorithm [1] is then applied to solve the single objective problem. We use the "Virtual Fruit" to determine the fitness of every individual in the population of solutions during the search process. Simulations were performed with a swarm population size of 14 particles, and a maximum number of generations of 20. The other parameters of the algorithm were the same as recommended in [1].

3 Results

We used the virtual fruit to simulate fruit quality of virtual genotypes, for two contrasted levels of tree fruit load and water stress. The genotypes were designed for three main traits involved in carbon growth, sugar metabolism and crack sensitivity. The optimization results of the aggregation approach reveal that, in the case where priority is given to any of the three criteria compared to the two others, the peach fruit will have a medium size (160g) and be very sweet (15%) and low sensitive to brown rot. However, when we optimize one criterion, such as fresh mass or sugar concentration, and transform the two others into constraints, we have what is currently in the market: a large fruit (300g), low sweet and sensitive to brown rot or a small fruit (120g), very sweet and low sensitive to brown rot.

4 Conclusion and perspective

We linked a process-based model to a heuristic optimization algorithm in order to design peach ideotypes with enhanced values for fruit quality and resistance aspects (brown rot sensitivity). The PSO algorithm was proved satisfactory for the specific problem examined in this work. Another algorithm MOPSO-CD that extends the particle swarm optimization to handle directly the multi-objective problem is currently developed. We shall compare the results of PSO approaches with other stochastic algorithms such as NSGA-II in order to offer the best tradeoff between simplicity, far-field accuracy and computational cost and conclude the most suitable method for the fruit quality.

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