The Relationship between Metaheuristics Stopping Criteria and Performances: Cases of NSGA-II and MOPSO-CD for Sustainable Peach Fruit Design

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ABSTRACT

A major difficulty in the use of metaheuristics (i.e. evolutionary and particle swarm algorithms) to deal with multi-objective optimization problems is the choice of a convenient point at which to stop computation. Indeed, it is difficult to find the best compromise between the stopping criterion and the algorithm performance. This paper addresses this issue using the Non-dominated Sorting Genetic Algorithm (NSGA-II) and the Multi-Objective Particle Swarm Optimization with Crowding Distance (MOPSO-CD) for the model-based design of sustainable peach fruits. The optimization problem of interest contains three objectives: maximize fruit fresh mass, maximize fruit sugar content, and minimize the crack density on the fruit skin. This last objective targets a reduction in the use of fungicides and can thus enhance preservation of the environment and human health. Two versions of the NSGA-II and two of the MOPSO-CD were applied to tackle this difficult optimization problem: the original versions with a maximum number of generations used as stopping criterion and modified versions using the stopping criterion proposed by the authors of (Roudenko & Schoenauer, 2004). This second stopping criterion is based on the stabilization of the maximal crowding distance and aims to stop computation when many generations are performed without further improvement in the quality of the solutions. A benchmark consisting of four plant management scenarios has been used to compare the performances of the original versions (OV) and the modified versions (MV) of the NSGA-II and the MOPSO-CD. Twelve independent simulations were performed for each version and for each scenario, and a high number of generations were generated for the OV (e.g., 1500 for the NSGA-II and 200 for the MOPSO-CD). This paper compares the performances of the two versions of both algorithms using four standard metrics and statistical tests. For both algorithms, the MV obtained solutions similar in quality to those of the OV but after significantly fewer generations. The resulting reduction in computational time for the optimization step will provide opportunities for further studies on the sustainability of peach ideotypes.

Keywords: Model-Based Design, MOPS-CD, Multi-Objective Optimization, NSGA-II, Particle Swarm Optimization, Performance Comparison, Stopping Criteria, Virtual Fruit Model

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1. INTRODUCTION

Contemporary fruit growers are confronted with a real challenge. They must not only address the impact of climate change on their farms, but they also must meet the social demand for healthy and high-quality products and reduced use of pesticides. Many studies have noted that fruit quality build-up and fruit sensitivity (i.e. resistance) to diseases result from interactive physiological processes. These processes also depend on the fruit genotype, on its environment, and, of course, on the cultural practices carried out by the fruit growers. Therefore, researchers believe that optimizing the genotype-by-environment-by-practices interactions could aid the fruit growers in facing the above-mentioned challenge. This optimization involves identifying a set of good combinations of genetic resources and cultural practices adapted to specific environments.

Given the complexity of fruit production systems, an integrative modeling approach is useful for studying the strong genotype-by-environment-by-practices interactions (Chenu et al., 2009; G.L. Hammer, Chapman, van Oosterom, & Podlich, 2005; G. L. Hammer, Kropff, Sinclair, & Porter, 2002; Reymond, Muller, Leonardi, Charcosset, & Tardieu, 2003). The idea is to use physiological models to analyze the plant traits and their development under the control of the environment and the genome (White & Hoogenboom, 2003; Yin, Kropff, & Stam, 1999; Yin, Struik, Tang, Qi, & Liu, 2005). The genetic information is included in the physiological models via the genetic parameters. Next, the combination of genetic parameters is optimized to design virtual ideotypes that are adapted to the target environments and cultural practices (Letort, Mahe, Courrède, De Reffye, & Courtois, 2008; Tardieu, 2003). This model-based design approach could contribute to reducing the number of time- and cost-consuming field experiments and could also lead to rapid identification of the best ideotypes and the evaluation of the long-term effects of climate change (Mayer, 2002; Ould-Sidi & Lescourret, 2011).

In a previous work, we proposed a model-based design approach to reduce the sensitivity of peach fruit to a storage disease (brown rot) while guaranteeing the fruit quality, therefore enhancing the ecological, economical and health benefits (Quilot-Turion et al., 2012). We used the ‘Virtual Fruit’ (Genard, Bertin, Gautier, Lescourret, & Quilot, 2010) model and formulated the studied case as a constrained Multi-objective Optimization Problem (MOP). The decision variables in our problem are six genetic parameters of the virtual fruit model identified via sensitivity analysis and based on expert choice. Three antagonist criteria related to fruit quality (fruit fresh mass and sugar contents) and its sensitivity to brown rot (crack density) must be optimized, and six bounding constraints must also be satisfied (Quilot-Turion et al., 2012). This formulation represents a relatively small but highly difficult multi-objective optimization problem. In addition to its nonlinear and non-convex nature, another difficulty in addressing this problem is the “black box” nature of the physiological models in general and of the “virtual fruit” in particular. Indeed, both the criteria and constraints of the formulated problem are black-box functions, i.e., we have no knowledge of the algebraic expressions of these functions in terms of the decision variables. Conventional optimization techniques, e.g., the gradient-based method, and linear, non-linear, and quadratic programming, are generally not adapted to this type of problem (Ramesh, Kannan, & Baskar, 2012), and more effective methods, e.g., the Multi-objective Evolutionary Algorithms (MOEAs)(Letort et al., 2008; Quilot-Turion et al., 2012) and Multi-Objective Particle Swarm Optimization (MOPSO) (Kadrani, Ould Sidi, Quilot-Turion, Genard, & Lescourret, 2012; Qi, Ma, Hu, de Reffye, & Courrède, 2010), have recently been proposed for this purpose. Therefore, we use one algorithm of each one of these two methods to address the model-based design of the virtual fruit ideotypes.

These population-based metaheuristics (i.e. MOEAs and MOPSO) are able to generate a set of “good” solutions, i.e., elements of the Pareto
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