INTRODUCTION

Production systems must adapt, in a changing climatic context, to face the growing social demand in terms of organoleptic, nutritional and environmental quality of food products. Fruit quality, even when reduced to organoleptic quality (such as sweetness or acidity) that meet consumer demand, is a multi-criteria concept. Moreover, it is well established today that the determinism of the fruit quality is multi-factorial: at least the fruit genome, environmental factors (light, temperature, water,...) and cultural practices influence fruit quality (Génard et al., 2007; Génard, Bertin, Gautier, Lescourret, & Quilot, 2010). On the other hand, dealing with storage disease resistance is a priority to reduce fruit residues and increase food safety. Among them, brown rot in peach fruits caused by Monilinia species can cause large economical losses.

It seems essential to propose new approaches to design sustainable systems that...
enhance fruit quality and reduce fruit sensitivity to brown rot. The strong genotype x environment x practices interactions in agricultural systems make it necessary to design genotypes that are adapted to specific agro-environmental conditions (Hammer, Kropff, Sinclair, & Porter, 2002). This issue is of increasing interest to the crop modeling community. Many researchers have analyzed plant traits via a model based on physiological mechanisms, which describes the development of traits through environment and genetic conditions namely by means of genetic parameters (Yin, Struik, Tang, Qi, & Liu, 2005). Thereafter, they optimize the combination of genetic parameters to design new ideotypes (Letort, Mahe, Cournede, De Reffye, & Courtois, 2008; Tardieu, 2003). An ideotype may be defined as a plant having a combination of such characters that enhance yield. To meet this challenge, researchers initially applied techniques such as trial and error (Haverkort & Grashoff, 2004; Herndl, Shan, Wang, Graeff, & Claupin, 2007). These attempts were quickly confronted to the difficulty and the hardness of the task. Indeed, the design of innovative cultivars is based on nonlinear and antagonistic criteria with respect to strong constraints (economic or environmental constraints such as water saving…).

In this context, the aim of the Peach-Rot Ideotype Modelling (PRIMo) project is to build-up a tool to conceive innovative management strategies that optimize genotype x environment x practices interactions to limit peach fruit contamination by brown rot while keeping or improving fruit quality. In the present case-study, we focus on the design of genetic material (ideotypes), performing virtual experiments for a given set of cultural practices and a specific environment. We used the ‘Virtual Fruit’ (Génard et al., 2007; Génard, Bertin, Gautier, Lescouret, & Quilot, 2010; Lescouret & Génard, 2005), a process-based model which simulates peach growth, to perform virtual experiments. The outputs of the ‘Virtual Fruit’ considered in this work are three fruit traits: fruit fresh mass, sugar concentration and skin density of cracks. The challenge is to design peach ideotypes that satisfy the requirement of high fruit quality (increasing fresh fruit mass and sweetness) and low sensitivity to brown rot (decreasing skin density of cracks).

This is a multi-objective optimization problem with nonlinear and conflicting criteria each being in a predefined bracket. Authors have used different ways to cope with multiple objectives. One of the most widely used methods for solving multi-objective optimization problems is to define one overall objective as the weighted sum of the multiple objectives considered. This approach has been used in agriculture (Amador, Sumpsi, & Romero, 1998; Gomez-Limon, Riesgo, & Arriaza, 2004) and forestry (Ananda & Herath, 2005). The Pareto methods are another way to deal with multiple objectives, as recently employed by (Letort et al., 2008; Qi, Ma, Hu, de Reffye, & Cournede, 2010; Quilot-Turion et al., 2012). Unfortunately, these approaches focus on the generation of the true Pareto front and disregard the decision making step since all criteria are considered to be of same importance (Coello, Veldhuizen, & Lamont, 2007).

In the problem examined here, the decision maker expects the preferred fruit traits to vary by market segment. Thus, the weight of each criterion is determined according to the importance of each objective, and the final solution depends on the perspective of the decision maker, who considers the relative importance of the conflicting objectives. For this reason, the Conventional Weighted Aggregation (CWA) method was selected for this study. However, the CWA might have some drawbacks as explained in Grabisch and Labreuche (2010) Jin, Okabe, and Sendhoff (2001).

The optimization process requires a suitable solution procedure that allows optimal values to be found with accuracy and robustness, especially regarding the initial values. For this type of problem, solution procedures based on deterministic methods tend to fail. Many metaheuristic techniques were proposed to deal with multiobjective optimization problems. The evolutionary algorithms, including Genetic Algorithms (GA), are among the most efficient
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