AVIS DE SOUTENANCE

THESE DE DOCTORAT

Présentée par

Mr: EL HASSAN SAKAR

Discipline : Biologie

Spécialité : Ecologie et Biodiversité

Sujet de la thèse : Phenological and pomological characterization of some almond (Prunus dulcis) cultivars grown in north-eastern Morocco.

Formation Doctorale : Sciences et Génie de la matière, de la Terre et de la Vie.

Thèse présentée et soutenue le mercredi 17 juillet 2019 à 15h au Centre des conférences devant le jury composé de :

Nom Prénom	Titre	Etablissement	
Said LOUAHLIA	PES	Faculté Polydisciplinaire de Taza	Président
M'Hammed EL KOUALI	PES	Faculté des Sciences Ben M'sik deCasablanca	Rapporteur
Ossama KODAD	PES	Ecole Nationale d'Agriculture de Meknès	Rapporteur
Abdeslam ENNABILI	PES	Ecole Supérieure de Technologie - Fès	Rapporteur
Khalil HAMMANI	PES	Faculté Polydisciplinaire de Taza	Examinateur
Abdelfettah ABDELLAOUI	PES	Faculté des Sciences Dhar El Mehraz de Fès	Examinateur
Yahia RHARRABTI	PES	Faculté Polydisciplinaire de Taza	Directeur de thèse

Laboratoire d'accueil : Ressources Naturelles et Environnement.

Etablissement : Faculté Polydisciplinaire de Taza.

Titre de la thèse : Phenological and pomological characterization of some almond (Prunus dulcis) cultivars grown in north-eastern Morocco.

Nom du candidat : El Hassan SAKAR

Spécialité : Ecologie et Biodiversité

Résumé de la thèse

Owing to their high nutritional and economical values, cultivated almond (*Prunus dulcis* [Mill.] D.A. Webb) is one of the most important nut trees grown worldwide. In Morocco, it is the main important among the rosaceous family. Despite its rank as the fourth global producer, Moroccan production (about 102085 tonnes of unshelled almonds, FAOSTAT 2019) fluctuates considerably from year-to-year and remains low as compared to USA and Spain. Moroccan orchards are mainly based on some commercial cultivars originated from France, Spain, and Italy. Occurrence of late-spring frost causes serious damage to almond flowers and fruitlet resulting in a lower productivity. The research works falling within the framework of this thesis focused on three main axes: phenological characterization, assessment of fruit physical traits, evaluation of kernel oil quality and almond cake as by-product of oil extraction. Our study concerned the main cultivars grown in Morocco 'Marcona', 'Fournat de Brézenaud', 'Ferragnès', 'Ferraduel', and 'Tuono'. To evaluate the effects of environmental conditions on phenology and fruit quality, our study was carried out across five different sites in northern (Aknoul, Bni Hadifa, and Tahar Souk) and eastern Morocco (Rislane and Sidi Bouhria) during three consecutive growing seasons (2016–2018).

In the first chapter, which was devoted to phenological characterization, we developed a phenological scale according to the code BBCH, different growth stages were identified, codified, and described. Phenological calendar in our cultivar was established under the study the conditions of northern Morocco. In the second part of this chapter, based on periodical visits and meteorological records in the 5 study sites we determined the chilling requirements (chilling units, CU) and heat requirements using GDD and GDH models for flowering and ripening. CU ranged from low for the early ('Marcona') and intermediate flowering time 'Fournat de Brézenaud') to high for late flowering time (the three remaining cultivars). GDD and GDH also differed significantly among cultivars and sites. The third part of this chapter was devoted to the evaluation of frost susceptibility of flower buds using chlorophyll fluorescence. The outcomes of this part indicate A linear decrease translated by frost susceptibility for late-flowering cultivars 'Ferragnés' and 'Ferraduel', and quadratic curve with an inflection point at -1°C indicating a chilling tolerance for 'Tuono' and the early-flowering cultivars 'Marcona' and 'Fournat de Brézenaud'. However, 'Ferragnés' and 'Ferraduel' (with later flowering date) are not likely to be affected by low temperatures at the end of spring when there is no risk of frost.

In the second chapter of this thesis, we evaluated some physical properties of almond nuts and kernels. Geometrical determinations were performed both in nuts and kernels, and consisted of the nine following parameters: length (L), width (W), thickness (T), arithmetic mean diameter (Da), geometric mean diameter (Dg), sphericity (Φ), volume (V), surface area (Sa) and projected area (Pa). ANOVA analyses showed that site, growing season, cultivar, and most of their interaction affected significantly all the parameters studied. L and Φ were genetically controlled, while T was environment-dependent for both nuts and kernels as well as Dg, V, Sa, Pa only for nuts. The rest of traits were equally determined by genotypic and environmental effects. Mean comparisons between cultivars showed that 'Marcona' and 'Fournat de Brézenaud' displayed the highest values of all geometrical properties. Gravimetrical measurements consisted in: In-hull weight, nut weight, kernel weight, hull percentage, shelling percentage, true density, bulk density, and porosity. The outcomes of ANOVA demonstrated that cultivar, site, growing season, and their interactions affected significantly most gravimetrical traits. In fact, hull percentage, kernel bulk density, and both nut true and bulk densities were mainly under genotypic dependency, while harvest season (climatic factor) was the main variability source in kernel weight. Furthermore, site (edaphic factor) was the most important in determining in-hull weight, nut weight, and kernel true density, while shelling percentage, and kernel and nut porosities were controlled jointly by genetic and edaphic factors. Wide variabilities were found between cultivars, sites, and harvest seasons for almost parameters as demonstrated by LSD's test. Almond kernels from our cultivars were medium ('Tuono', 'Ferraduel', 'Ferragnès', and 'Marcona'), and large (cv. 'Fournat de Brézenaud'). Furthermore, corresponding nuts were hard (cvs. 'Fournat de Brézenaud', 'Tuono', and 'Ferragnès') to very hard shelled (cvs. 'Ferraduel' and 'Marcona'). Among sites, fruits harvested from sites of eastern Morocco performed better in terms of in-hull weight, nut weight, and kernel weight, bulk density, and true density. Whereas, Aknoul and Tahar Souk (northern Morocco) had the greatest values of hull percentage and both nut and kernel porosities. Principal component analysis (PCA) allowed a good discrimination among cultivars, sites, and growing seasons. The first component was of genetic order along which cultivars were separated, while the second and the third components exerted together an environmental control since they separated sites and growing seasons, respectively. Significant correlations were highlighted among studied characteristics. The most important ones were modeled through simple regressions and therefore they can be used to predict each other. Kernel color indices consisted of the six following traits: brightness index (L*), redness index (a*), yellowness index (b*), chroma (C*), hue (H*), and metric saturation (S*). The outcomes of ANOVA demonstrated significant effects of all factor (cultivar, growing

season, and site) and site by cultivar interaction on almost studied kernel color properties. However, the majority of these properties was genotypic dependent. There were wide variabilities among the five cultivars in terms of most color indices. 'Marcona' showed the highest L*, while 'Ferragnès' and its pollinator 'Ferraduel' displayed greater scores of a*, b*, C*, and S*. Among sites, Sidi Bouhria was found to have the lowest L* but higher values of a*, H*, and S*. Moreover, Bni Hadifa displayed higher L*, b*, and C*. For growing seasons, 2016 had the highest values of most color indices. Principal component analyses (PCA) discriminate between all factor through the first three component. PC1 (61%) was of genetic extent, while PC2 (30%) and PC3 (7%) were of environmental nature since they separate sites and growing seasons, respectively.
The third chapter was devoted to assessment some almond oil quality traits and determination of nutritional quality of almond cake. After press extraction, Oil yield (OC) was calculated. Oil quality determinations consisted of polyphenols content (PP), acid value (AV), peroxide value (PV), and UV absorption coefficients (K232 and K270). Fatty acids composition was determined using CG/MS for 2017 growing season for Aknoul and Sidi Bouhria. Total saturated fatty acids (SFA), monounsaturated fatty acids (MUFA), polyunsaturated (PUFA), and ratio Oleic acid/ Linoleic acid (O/L) were computed. The outcomes of ANOVA showed that all factor (cultivar, site, growing season) and most of their interactions affected significantly the studied physico-chemical traits. For all the studied traits, cultivar was the main source of variability. 'Marcona' showed its superiority for OC (57.70 % DM), while 'Fournat de Brézenaud' presented the highest values of PP (0.84 mg GA/g oil), AV (0.90 % Oleic acid), and PV (0.42 meqO2/kg of oil). The highest values of K232 (1.99) et K270 (0.20). Among sites, Sidi Bouhria showed the greatest OC (54.57), PP (0.81), K232 (1.71), and K270 (0.17). Concerning growing season, 2016 was characterized by its higher scores of OC (55.57), PP (0.82), AV (0.76), PV (0.36), K232 (1.52), and K270 (0.14). Our results for fatty acids revealed the presence of 11 fatty acids with wide variabilities between cultivars and sites. However, the majors were: Oleic (C18 :1), linoleic (C18 :2), palmitic (C16 :0), stearic (C18 :0), and palmitoleic (C16 :1). MUFA (mainly C18 :1) were most important among fatty acids followed by PUFA (mostly C18 :2) and SFA (C16 :0). O/L ratio is a good kernel quality criterion, higher values of this ratio indicate higher oil stability and kernel quality. In our results, O/L varied significantly among cultivar with the highest value found in 'Ferraduel' (4.55) and the lowest one in 'Fournat de Brézenaud' (3.20). PCA carried out allowed a clear separation of cultivars along PC1 (60%), while sites were discriminated through PC2 (19%). Important correlations were highlighted between oil traits. O/L was regressed separately against oleic and linoleic acids, the outcomes of these results showed that O/L could predicted from these fatty acids with an accuracy higher than 99%. These results demonstrated that oil samples obtained were generally of excellent quality with low values of AV, PV, K232, and K270 on one hand and higher values of PP and O/L on the other hand. In order to characterize almond cake as by-product of almond, we evaluate proteins, moisture, ash, residual oil, carbohydrates, energy value and pH in the press cake. ANOVA analyses showed significant effects of cultivar, growing season, and site. Among cultivars 'Marcona' showed the highest value of residual oil and energy value, 'Fournat de Brézenaud' presented the best score of proteins, and 'Ferragnès' displayed the greatest value of ashes and carbohydrates. With respect to sites, the eastern sites exhibited the greatest values of proteins, residual oil, ashes, energy value but lower moisture content and carbohydrates. Concerning growing seasons, 2018 was a rainy year resulting in almond oil cake of higher moisture, but lower proteins, ashes, residual oil, and therefore lower energy value. Principal component analysis (PCA) when applied to our results allowed a better discrimination of cultivars along PC1 (genetic component), and sites on PC3, and growing seasons on PC3 and PC2, respectively (environmental components). Important correlations were outlined between some traits.

Keywords: Phenology, BBCH scale, thermal requirements, pomological traits, kernel oil, almond cake, genotypic and environmental effects, multivariate statistical analysis