Summary

The research works falling within the framework of this thesis were 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', and 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.

In the first chapter, which was devoted to phenological characterization, we developed a phenological scale according to the BBCH code in which different growth stages were identified, codified, and described. We identified eight of the ten principal stages (0 − 9) from BBCH scale: development of bud (stage 0), leaf (stage 1), shoot (stage 3), inflorescence (stage 5), flowering (stage 6), fruit development (stage 7), maturity (stage 8), and dormancy (stage 9). Phenological calendar of the studied cultivars was established. In the second part of this chapter, and based on periodical visits and meteorological records in the five 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, sites, and growing seasons. The third part of this chapter was devoted to the evaluation of frost susceptibility of flower buds using chlorophyll fluorescence (Fv/Fm). The outcomes of this part indicate a linear decrease of Fv/Fm 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 ('Marcona') and intermediate-flowering ('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 (D_a), geometric mean diameter (D_g), sphericity (Φ), volume (V), surface area (S_a) and projected area (P_a). Gravimetrical measurements consisted in: In-hull weight (HW), nut weight (NW), kernel weight (KW), hull percentage (HP), shelling percentage (SP), true density (ρ_t), bulk density (ρ_b), and porosity (ε). Kernel color indices were as follows: Brightness index (L*), redness index (a*), yellowness index (b*), chroma (C*), hue angle (H*), and metric saturation (S*). Wide variabilities were found between cultivars, sites, and growing seasons for almost parameters. Physical fruits traits studied here were found to be environment-dependent (T in both nuts and kernels, D_g, V, S_a, Pa only for nuts, KW, HW, NW, and ρ_t in kernels, and H*), under genetic dependency (L and Φ, HP, ρ_b in kernels, and both ρ_t and ρ_b in nuts, L*, a*, b*, C*, and S*), or equally determined by genotypic and environmental effects (remaining traits). Significant correlations were highlighted among studied characteristics and the most important ones were modeled through simple and multiple regressions.

The third chapter was devoted to the assessment of quality of kernel oil and cake. After press extraction, kernel oil content was calculated. Oil quality determinations consisted of polyphenols content, acid value, peroxide value, and UV absorption coefficients. Fatty acids composition was determined. Total saturated fatty acids (SFA), monounsaturated fatty acids (MUFA), polyunsaturated (PUFA), and ratio Oleic acid/ Linoleic acid (O/L) were computed. To characterize almond cake as a by-product of almond, we evaluate proteins, moisture, ash, residual oil, carbohydrates, energy value and pH in the press cake. For most of the studied traits, cultivar was the main source of variability. Our results for fatty acids revealed the presence of 11 fatty acids with wide variabilities between cultivars and sites. However, the majors were: Oleic acid, linoleic acid, palmitic acid, stearic acid, and palmitoleic acid. MUFA were most important among fatty acids followed by PUFA and SFA. In our results, O/L ranged from 3.20 in ('Fournat de Brézenaud') to 4.55 found in ('Ferraduel'). These results demonstrated that oil samples obtained were generally of excellent quality with low values of AV, PV, K_{232}, and K_{270} on one hand and higher values of PP and O/L on the other hand. Almond cake had higher contents of proteins, residual oil, ashes, carbohydrates, and energy value with significant differences among cultivars, sites, and growing seasons. '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. With respect to sites, the eastern sites exhibited the greatest values of proteins, residual oil, ashes, energy value but lower moisture content and carbohydrates. Important correlations were outlined between some traits.

Keywords: Phenology, BBCH scale, chilling and heat requirements, fruit quality, pomological traits, kernel oil, almond cake, genotypic and environmental effects, multivariate statistical analysis.