Massive almond tree mortality in the central High Atlas, Morocco

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Abstract

Morocco has been experiencing six consecutive years of drought due to a decline in rainfall linked to climate change and this have threatened water supplies and hit agriculture and the economy in general. The main objective of the article is to document the sudden massive death of almond trees in the central High Atlas Mountains during 2022-2025. In March-August 2022, an average of 24.7% of dead trees was identified among the 4 074 almond trees in the study area. This average has increased to 88.2% in February-August 2024. In all the 17 studied fields, the average number of dead trees has risen rapidly in 2023. The results of monitoring almond trees in the field showed that tree mortality occurred mainly between March 2023 and July 2023, and that since September 2023, 88.2% of trees became totally dead. In the study area, almond trees play very important economic and ecological roles. Therefore, it is necessary to quickly find solutions to protect the remaining almond trees, as well as to help farmers and residents to obtain knowledge, techniques and funding necessary to carry out a regional campaign to plant almond trees in areas where trees have died.

Keywords: Almond decline, tree mortality, Morocco, Drought

INTRODUCTION

The almond (*Prunus dulcis* (Mill.) D.A. Webb; syn. *Prunus amygdalus* Batsch) is native to southwest Asia, especially the arid mountains of Iran, Afghanistan, and in western China (Grasselly, 1976; Kester and Gradziel, 1996). It was spread by humans in ancient times, and has been cultivated by the Egyptians, Greeks and Romans throughout the Mediterranean, North Africa and Southern Europe (Casas-Agustench *et al.*, 2011). Almonds thrive in the mild climate of the Mediterranean (Loussert *et al.*, 1989). They are very well-adapted to dry and sunny climates (Vidaud, 1982). Almond trees are typically 4-6 m high, but they can grow up to 10 m (Loussert *et al.*, 1989).

Almonds are the second fruit tree culture in importance after olive trees in Morocco with an area of 128,000 hectares (Laghezali, 1985; Walali and Rakii, 1999). Morocco ranks fifth among the nations of the world in almond production (Ibourki *et al.*, 2019). In Morocco, almond plantations play a very important socio-economic role and contribute to community development and economic growth (Charifi Alaoui, 2003). The almond is one of the most polymorphic cultivated fruit species due to the genetically controlled self-incompatibility system (Martínez-Gómez *et al.* 2007; Halász *et al.*, 2019) and several studies showed the existence of a wide variability and quality of nuts within the Moroccan almond population (Elhamzaoui *et al.*, 2012). Morocco has seen through the Green Morocco Plan a massive introduction of new varieties of almond trees (Kodad *et al.*, 2020).

Morocco has been experiencing six consecutive years of drought due to a drop in rainfall linked to climate change and this have threatened water supplies and hit agriculture and the economy in general. Droughts have noticeable effects on spontaneous and cultivated plants, air, soil, freshwater quality, and the fauna in the central High Atlas of Morocco (e.g., El Alami, 2019; El Alami *et al.*, 2020; El Alami and Chait, 2020; El Alami, 2022). Drought seasons and climatic fluctuations severely affect the agricultural sector. Although almond tree is generally recognized as drought-tolerant, the last six years of drought have a negative impact on almond cultivation and production in Morocco. The main objective of the article is to document the sudden massive death of almond trees in the central High Atlas Mountains during 2022-2024.

MATERIALS AND METHODS

Study area

The study region is located in the mountains of Bni Ayat, in the Moroccan central High Atlas of Azilal (Figure 1). This area was chosen because it includes a significant number of almond fields and is known for its high production. The second reason is that it is the area where the first author of this article has been conducting his research on biodiversity since 2003. The altitude ranges from 450 to 1700 m. The area's climate varies from semi-arid to sub-humid and is characterized by a cold winter and summer drought (Ouchbani and Romane, 1995). The study area consists of non-forested terrain, small agricultural land, forests and brushwood. The natural habitat types in the study area are mainly the resin spurge *Euphorbia resinifera*, the wild olive *Olea europaea var. sylvestris,* the carob *Ceratonia siliqua*, the Barbary Thuya *Tetraclinis articulata,* the prickly juniper *Juniperus oxycedrus,* the lentisk *Pistacia lentiscus*, holm oak *Quercus ilex*, and Phoenician juniper *Juniperus phoenicea* (Ouchbani and Romane,

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1995; El Alami *et al.*, 2013; El Alami, 2022). The main land uses are agriculture and pastoralism. The most cultivated plant trees are olive and almond. In this area, the olive tree is planted in irrigated lands and the almond tree is planted in non-irrigated lands and it is the second most important cultivated tree after the olive tree. The surveyed almond fields were in the villages and sites of Rjam, Sidi Brahim, Tizgui, Ifarghas, Tagantn'Ifarghas and Takaroute-Ait Imloule (Table 1).

Data collection

This study was conducted between January 2022 and January 2025. In order to monitor the almond cultivations, field surveys were carried out. We chose 17 almond fields, located in six sites in the study region (Table 1). Each field corresponds to a set of land cultivated with almond trees, which are owned by one or more local residents. In most cases, almond trees are mixed with spontaneous trees such as *Euphorbia resinifera*, *Olea*

Table 1: Total number of almond trees and the number of dead trees in the 17 fields, located in six sites in the study region in March-August 2022 and February-August 2024 (geographic coordinates of the study regions and percentages of number of dead trees are in parentheses)

Site name (Geographic coordinates)	**Altitude (m)**	**Filed number**	**Total number of trees in March-August 2022**	**Number of dead trees in March-August 2022(%)**	**2023**	**Number of dead trees in February-August 2024(%)**
Sidi Brahim (32.204145, -6.578768)	500-680 m	1	114	26 (22.8 %)	**Massive almond tree mortality**	102 (89.5 %)
		2	294	43 (14.6 %)		289 (98.3 %)
Tizgui (32.206283, -6.583617)	480-700 m	3	208	23 (11.0 %)		198 (95.2 %)
		4	185	37 (20.0 %)		154 (83.2 %)
		5	137	42 (30.7 %)		129 (94.2 %)
		6	95	23 (24.2 %)		88 (92.6)
Ifarghas (32.204318, -6.588348)	600-750 m	7	342	64 (18.7 %)		311 (90.9 %)
		8	174	35 (20.1 %)		146 (83.9 %)
		9	217	39 (18.0 %)		186 (85.7 %)
		10	108	49 (45.4 %)		102 (94.4 %)
Tagant n'Ifarghas (32.213187, -6.593691)	550-650 m	11	359	161 (44.8 %)		317 (88.3 %)
		12	168	71 (42.3 %)		152 (90.5 %)
Takaroute-Ait Imloule (32.184984, -6.607413)	900-1150 m	13	632	53 (8.39 %)		492 (77.8 %)
Rjam (32.205984, -6.564927)	460-550 m	14	92	37 (40.2 %)		86 (93.5 %)
		15	427	85 (19.9 %)		395 (92.5 %)
		16	188	56 (39.8 %)		160 (85.1 %)
		17	334	87 (26.0 %)		212 (63.5 %)
Total	460-1150 m	17 fields	4074	931 (25.7 %)		3519 (88.2 %)

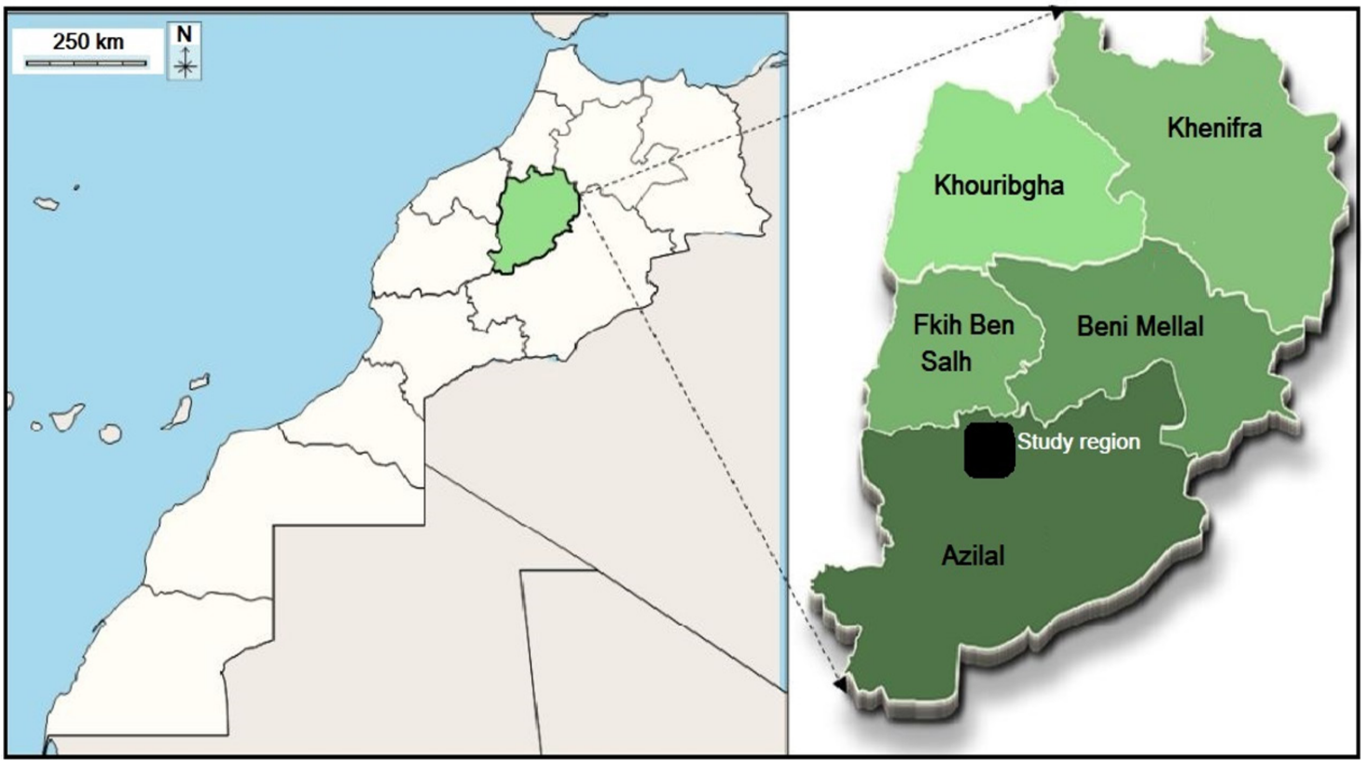

Figure 1: Location of the study area in the national and regional maps

europaea var. sylvestris, Ceratonia siliqua, Tetraclinis articulata, Juniperus oxycedrus, and *Pistacia lentiscus*.

In this study, we counted the number of almond trees in each field and determined the number of the dead trees. The first count was done in March-August 2022 and all living and dead almond trees were counted. The trees found dead in this period are all trees that died before 2022 and have not yet been uprooted by farmers.

The second count was in February-August 2024. Trees found dead in second count were all trees that died in 2023 period. Then we calculated the percentages of the dead trees in the two periods. For an almond tree, it is easy to spot a dead tree. The signs that can help identify a dead tree are: 1) lack of leaves, 2) dry and brittle branches, and 3) cracks in the trunk. Dying trees were not considered in the count of dead trees. Dying tree signs are: 1) presence of some wilted or brown leaves and 2) presence of some wet and live branches. These plants will be counted in later studies, when they will be completely dead or alive.

RESULTS AND DISCUSSION

During March-August 2022, a total of 4 074 almond trees, live and dead, were identified in 17 fields, spread across the six study sites: 408 trees in Sidi Brahim, 625 in Tizgui, 841 in Ifarghas, 527 in Tagant n'Ifarghas, 632 in Takaroute-Ait Imloule, and 1041 trees in Rjam (Table 1). Evolution of the percentages of dead trees in each site and field were detailed in the Table 1.

In March-August 2022, an average of 24.7% of dead trees was identified among the 4 074 almond trees in the study area. In February-August 2024, this average has increased to 88.2%, which means that 2 588 trees died in the year 2023.

In the all 17 studied fields, the average number of dead trees has risen rapidly in 2023 (Figure 2 and Figure 3). This average has risen above 90% in nine fields: the field 1 located in the Sidi Brahim region, in the fields 3, 5 and 6 in the Tizgui region, in the fields 7 and 10 in the Ifarghas region, in the field 12 in the Tagant n'Ifarghas region, and in the fields 14 and 15 in the Rjam region.

This average of dead trees has risen above 80% in six fields: in the field 1 in the Sidi Brahim region, in the field 4 in the Tizgui region, in the fields 8 and 9 in the Ifarghas region, in the field 11 in the Tagant n'Ifarghas region, and the field 16 in the Rjam region. In the field 13, located in the Takaroute-Ait Imloule region, the average of dead trees increased to 77.8% and to 63.5% in the field 17 in the Rjam region.

The results of monitoring almond trees in the field, and especially those existing in fields belonging to the authors' family (Figure 4), showed that tree mortality occurred mainly between March 2023 and July 2023. Before March 2023, 74.3% of trees were alive, green with good foliage (Table 1; Figure 4a, 4b, 4c and 4g) or with flowers (Figure 4d, 4e and 4f). Although, in March 2023, the trees were alive and green, field observation showed that the majority of them started to dry out rapidly in

Figure 2: Views of four studied almond fields, in the central High Atlas of Azilal, before 2023 (2020-2022): most trees are alive, green and healthy with a significant number of flowers during the flowering season (Photographed by the author)

Figure 3: Views of six studied almond fields, in the central High Atlas of Azilal, after 2023 (2024-2025): almost all the almond trees are dead, bearing dry branches without leaves (the plants that appear green in the pictures are olive, carob and resin spurge) (Photographed by the author)

April 2023. In May 2023, the majority of the branches became dry with only a few green branches (Figure 4h). In July 2023, the majority of trees became dead and dry, with the presence of very few living branches (Figure 4i). Since September 2023, 88.2% of trees became totally dead (Figure 4j and 4k; Table 1). It was observed that most of the trees dried up and died in masse during the period from March 2023 to July 2023, in all the studied fields.

The almond tree is of a great socio-economic interest for local population in the central High Atlas Mountains. Almond crops provides incomes for local people and are used in human food, cosmetics and herbal medicine, the wood is used as fuel, the leaves and fruits constitute fodder for goats and sheep, and the oil extracted from the almond is used in cosmetics and human food (Faouzi, 2011).

The piedmont and mountains of the Atlas Mountains, where the almond trees are concentrated, are experiencing a notable decline and they are subject to climate change impacts, deforestation and overgrazing (El Alami, 2019; El Alami *et al.*, 2020; El Alami and Chait, 2020; El Alami, 2022).

The climate is a key factor affecting plant growth and development of the almond tree and climate change can have major impacts on its production (Freitas *et al.*, 2023). Until this day (23 February 2025), annual total precipitation reductions, heat waves and droughts remain in Morocco. In Mediterranean arid or semi-arid climates, seasonal drought combined with heat waves and limited irrigation water supplies result in a rapid decline in plant water status and the intense defoliation and tissue dehydration occur, which can trigger plant mortality (Goldhamer and Smith,1995; Moldero *et al.*,2021; Fernandes de Oliveira *et al.*, 2023).

CONCLUSION

In Morocco, almond rank second after olives production (Goura *et al.*, 2023). It covers an area of approximately 186,000 hectares in 2018 with a production yield of about 0.63 tons per hectare (Boulika, 2025). Moroccan almond imports from the United States reached a record in 2024, with 35,000 tonnes of shelled almonds imported during the first 11 months of the year and these imports, valued at 174.5 million dollars, mark an increase of 18 % compared to the same period in 2023 (Oukerzaz, 2025).

In addition, the death of almond trees will have a major impact on the local economy in the central High Atlas Mountains, given that almond crops are one of the most important economic resources for the local populations. Almond trees also play very important ecological roles, especially because they are among the most important trees that protect the soil from erosion in these areas, and also because almonds are important for many animals such as squirrels, birds and insects. Therefore, it is necessary to work quickly to find solutions to protect the remaining almond trees, as well as to help farmers and residents to obtain knowledge, techniques and

***Figure 4: Tracking two almond trees mortality with photos (2017-2024) in the central High Atlas of Azilal** (Photographed by the author)*

funding necessary to carry out a regional campaign to plant almond trees in areas where trees have died. It is also essential to conduct scientific studies to understand all the factors that control the growth and production of almonds in the High Atlas Mountains.

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g (22 March 2023)

h (28 May 2023)

i (22 July 2023)

j (10 September 2023)

K (24 November 2024)

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