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Strengthening the climate resilience of local products through appropriate post-harvest valorization models

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Abstract **-** Several Moroccan agricultural sectors are rich of resilient local products with the capacity to resist to climate change. The characterization, valorization, and promotion of these products are among the priorities of national agricultural strategies. Through this article, the case of six local or terroir products from resilient cultures (cactus, legumes, olive oils, dates, aromatic and medicinal plants, and carobs) is illustrated by presenting appropriate models of research and development actions in terms of post-harvest valorization. These resilient terroir products are perfectly suitable for the development of specific terroirs in arid and semi-arid zones and play an important role in food security, preservation of biodiversity as well as socio-economic development of rural communities. They are also appreciated on local, national, and international markets for their notoriety, typicity, and quality. Consequently, prospective research will be oriented more towards the consolidation of National Institute of Agricultural Research (INRA) expertise in the areas of valorization and promotion of resilient terroir products. This objective can be reached through an innovative and multidisciplinary research making it possible to predict and mitigate the effect of climate change on the intrinsic and extrinsic qualities of these products as well as the viability and sustainability of their value chains.

Keywords: *Climate change, resilience, terroir products, post-harvest valorization, Morocco.*

Renforcement de la résilience climatique des produits de terroir à travers des modèles appropriés de valorisation post-récolte

Résumé **-** Plusieurs filières agricoles marocaines regorgent de produits de terroir résilients ayant la capacité de résister aux changements climatiques. La caractérisation, la valorisation et la promotion de ces produits figurent parmi les priorités des stratégies agricoles nationales. A travers cet article, le cas de six produits de terroir issus de cultures résilientes (cactus, légumineuses, huiles d'olive, dattes, plantes aromatiques et médicinales et caroubes) est illustré en présentant des modèles appropriés d'actions de recherche et de recherche et développement en matière de la valorisation post-récolte. Ces produits de terroir sont parfaitement convenables pour la mise en valeur des terroirs spécifiques au niveau des zones arides et semi-arides et jouent un rôle important dans la sécurité alimentaire, la préservation de la biodiversité ainsi que le développement socio-économique des communautés rurales. Ils sont également appréciés sur les marchés locaux, nationaux et internationaux pour leur notoriété, typicité et qualité. De ce fait, les recherches prospectives seront orientées davantage vers la consolidation de l'expertise de l'Institut National de la Recherche Agronomique (INRA) dans les domaines de la valorisation et de la promotion des produits de terroir résilients à travers une recherche novatrice et multidisciplinaire permettant de prédire et mitiger l'effet des changements climatiques sur, d'une part, les qualités intrinsèque et extrinsèque de ces produits et d'autre part, sur la viabilité et la durabilité de leurs chaînes de valeur.

Mots-clés : *Changements climatiques, résilience, produits de terroir, valorisation post-récolte, Maroc.*

تعزيز المرونة المناخية للمنتجات المجالية من خلال نماذج مناسبة للتثمين ما بعد الجني

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ملخص-تزخر العديد من القطاعات الزراعية المغربية بالمنتجات المجالية التي لديها القدرة على مقاومة التغير المناخي. ويعد تصنيف وتثمين هذه المنتجات والترويج لها من بين أولويات الاستراتيجيات الزراعية الوطنية. من خلال هذا المقال، يتم تسليط الضوء على ست منتجات مجالية من الزراعات المقاومة وهم الصبار والقطاني وزيت الزيتون والتمور والنباتات العطرية والطبية والخروب، من خلال تقديم نماذج مناسبة من أنشطة البحث والبحث والتنمية خلال مرحلة التثمين ما بعد الجني. وتعتبر هذه المنتجات المجالية المرنة مناسبة لتنمية مجالات محددة في المناطق القاحلة والشبه القاحلة كما تلعب دورًا مهمًا في الأمن الغذائي والحفاظ على التنوع البيولوجي بالإضافة إلى التنمية الاجتماعية والاقتصادية للساكنة القروية. وتحظى كذلك بالتقدير في الأسواق المحلية والوطنية والدولية لسمعتها وخصائصها وجودتها المتميزة. ونتيجة لذلك، سيتم توجيه البحوث المستقبلية بشكل أكبر نحو تعزيز خبرة المعهد الوطني للبحث الزراعي في مجالات تثمين المنتجات المجالية المرنة من خلال بحوث مبتكرة ومتعددة التخصصات التي تجعل من الممكن التنبؤ بتأثير تغير المناخ والتخفيف منه على الجودة الداخلية والخارجية لهذه المنتجات وعلى جدوى واستدامة سلاسل القيمة الخاصة بها.

الكلمات المفتاحية: *تغير المناخ، مرونة، منتجات المجالية، تثمين ما بعد الجني، المغرب*

Introduction

The concept of resilience is increasingly applied to agriculture, sustainable food systems and agricultural value chains. All links in these chains, from upstream to downstream, must adapt to current challenges and risks related to climate change, evolving market situations and growing demands of consumers and society (IPCC, 2022).

Several Moroccan agricultural sectors are full of a range of resilient local or terroir products with the capacity to resist climate change. Indeed, Morocco is a country with great pedoclimatic, and geographical diversity having favored the emergence of several resilient local products (MAPMDREF, 2023a).

National agricultural strategies, notably the Plan Maroc Vert (PMV) 2010-2020 and the Generation Green (GG) 2020-2030, have supported these local products for appropriate valorization and promotion. In the second pillar of the GG strategy relating to the sustainability of agricultural development, INRA research achievements are of great importance. In fact, they contribute to the consolidation and the resilience of agricultural sectors through the valorization and promotion of local products by highlighting their typicity. The GG strategy also aims to promote the labeling of Moroccan local products under distinctive signs of origin and quality (SDOQ) allowing quality improvement. It also allows the preservation of local population's know-how and the promotion of agriculture in rural, semi-arid, and arid areas, capable of conserving biodiversity and valorizing natural resources (MAPMDREF, 2023b).

Through this article, the case of six Moroccan local products from resilient cultures, chosen for their social, economic, and environmental importance is illustrated (cactus, legumes, olive oils, dates, aromatic and medicinal plants and carobs) by highlighting emphasis on research and development achievements based on models of post-harvest valorization actions carried out by INRA in collaboration with its national and international scientific and development partners. These research actions are focused on various aspects of valorization, including quality characterization, typicity determination, transformation processes and new products development, preservation processes adaptation, SDOQ establishment, transfer of technologies, and capacities strengthening of local products valorization units. These models of resilient local products play an important role in food security, biodiversity preservation, and socio-economic development of rural communities. They are also appreciated on local and international markets for their quality and typicity.

Cactus valorization

Cactus and climatic resilience

The cactus or prickly pear (*Opuntia* spp.) occupies a key place economically and in environmental protection in arid and semi-arid areas. It has the capacity to adapt to the most extreme soil and climatic conditions and it is known to be very efficient in the use of water. These qualities have prompted several countries to take an interest in its development and valorization (Lahmidi *et al.*, 2023).

In Morocco, the strong revival of interest observed over the last two decades is due to the multiple uses of the cactus in terms of: (i) environmental for the protection and rehabilitation of soils, (ii) food-related for human and animal nutrition, and (iii) agro-industrial and cosmetic for fruit and cladode processing, oil extraction from seeds, and development of other derivatives (Lahmidi *et al.*, 2023).

In their scientific and development approaches, research activities concerning cactus valorization aim to contribute to the promotion and development of this sector. The covered aspects regarding different parts of the plant are diversified and concern the characterization of nutritional, sensory, commercial and technological qualities allowing an orientation towards an appropriate valorization and the development of transformation processes into various products for food, pharmaceutical, or cosmetic uses. Research findings

are promoted through technology transfer and capacity building of cactus valorization units (CRRA, 2018).

Characterization of cactus ecotypes

The dietary, cosmetic, and medicinal importance of the cactus requires a better knowledge of its ecotypes. Several characterization research activities were carried out at INRA, Regional Center for Agricultural Research (CRRA) in Marrakech on the pulp, peel, cladode, flower, seed, and oil. Below are presented some results of this characterization work carried out in collaboration with the CRRA Errachidia and which focused on around twenty ecotypes belonging to several species such as *Opuntia ficus-indica* (L.) Mill., *Opuntia megacantha* Salm-Dyck, *Opuntia stricta* (Haw.) Haw., and *Opuntia robusta* H.L. Wendl. ex Pfeiff.

Concerning the fruit pulp, nutritional, technological, commercial, and organoleptic qualities were determined through the study of the physical, physicochemical, biochemical, and sensory parameters of several ecotypes from different regions (CRRA, 2018; Homrani Bakali *et al.*, 2021). For cladodes, part of cactus rich in nutrients with multifunctional properties (fibers, mucilages, antioxidants, etc.), it was carried out the evaluation of the suitability of cladodes of different ages for processing into powder and the determination of technological and nutritional qualities of the obtained powders. This powder has different and interesting characteristics allowing it to be oriented towards distinct uses. It could be used as an ingredient in food preparations (cookies, creams, desserts, etc.), cosmetic products (creams, shampoo, lotions, etc.), and pharmaceutical products (gastroprotective mucilage extracts, capsules, tablets, etc.) (CRRA, 2018; Harrak, 2021; Lahmidi *et al.*, 2023).

The characterization studies have extended to both fresh and dried fruit peels, with a focus on assessing the impact of drying methods on the nutritional and organoleptic properties of these peels. Rich in bioactive compounds and natural pigments, notably betalains including betacyanins (red-purple pigments) and betaxanthins (yellow-orange pigments), the powder of these peels is recommended for agro-industrial, cosmetic, and medicinal uses (Ettalibi *et al.*, 2020a).

Dried flowers are the part of the plant most used to prevent and treat many diseases. Their herbal tea, in infusion or decoction, is recognized in traditional pharmacopoeia for its therapeutic virtues. Research carried out on these flowers concerned the determination of their physicochemical, biochemical, and antioxidant properties for the evaluation of nutritional and commercial qualities (CRRA, 2018).

Cactus fruit seeds have multiple benefits for the skin. The research focused on characterizing the seed powder and oil of various ecotypes, examining bioactive compounds as well as quality and purity parameters such as fatty acid and triglyceride profiles. They also concerned the study of different factors of the oxidative stability of this oil during storage and the detection of levels of its adulteration by vegetable oils such as olive, almond, rapeseed, and sunflower oils for quality control. The fatty acid profile of seed oil extracted from fruits of 9 ecotypes of *Opuntia* spp. representing three species: *Opuntia ficus-indica* (L.) Mill., *Opuntia megacantha* Salm-Dyck, and *Opuntia stricta* (Haw.) Haw. produced in the oasis zone of South-East Morocco (Drâa - Tafilalet region) is interesting from both nutritional and cosmetic uses with high degree of unsaturation and majority composition of linoleic acid (omega 6), oleic acid (omega 9), and palmitic acid (Table 1) (Ettalibi *et al.*, 2020b; Ettalibi *et al.*, 2021; Harrak *et al.*, 2023).

Table 1. Fatty acids profile (%) of seed oil of fruits of 9 ecotypes of *Opuntia* spp. belonging to the species *Opuntia ficus-indica* (L.) Mill. (OF), *Opuntia megacantha* Salm-Dyck (OM), and *Opuntia stricta* (Haw.) Haw. (OS) (Harrak *et al.*, 2023).

Ecotype	C16:0	C16:1 w9	C16:1 w7	C17:0	C17:1	C18:0	C18:1w 9	C18:1w 7	C18:2	C18:3	C20:0	C20:1	C22:0
P17 (OS)	11.67	0.04	0.11	0.04	0.04	3.93	9.52	4.72	68.98	0.40	0.17	0.17	0.21
P99 (OF)	10.40	0.10	0.53	0.05	0.04	5.08	22.10	4.76	55.61	0.45	0.25	0.37	0.26
P115 (OM)	10.92	0.09	0.60	0.05	0.05	4.24	19.54	5.28	58.18	0.36	0.20	0.31	0.19
P37 (OF)	10.77	0.10	0.56	0.05	0.08	4.34	21.61	5.07	56.05	0.50	0.21	0.41	0.26
P98 (OM)	10.82	0.10	0.53	0.05	0.05	5.19	24.60	4.78	52.57	0.54	0.22	0.34	0.20
P183 (OF)	10.53	0.11	0.33	0.31	0.04	2.69	21.64	5.22	57.73	0.54	0.34	0.35	0.21
P112 (OF)	10.18	0.10	0.49	0.04	0.06	5.62	22.61	4.74	54.72	0.53	0.24	0.38	0.29
P16 (OM)	10.91	0.10	0.54	0.06	0.04	4.80	17.92	4.91	59.22	0.49	0.27	0.38	0.35
P19 (OF)	10.05	0.10	0.47	0.06	0.04	5.44	16.49	4.66	61.21	0.54	0.29	0.40	0.25

Development of cactus transformation processes

The research activities carried out at INRA (CRRA Marrakech) in their research and development and socio-economic approaches on cactus transformation processes of species *Opuntia ficus-indica* (L.) Mill., *Opuntia megacantha* Salm-Dyck, and *Opuntia stricta* (Haw.) Haw., have enabled the development of transferable and income-generating processing technologies, namely fruit and cladode jams and juices, canned cladode fillets, cladodes and fruit peels powder, and seeds oil (Fig. 1) (CRRA, 2018; Ettalibi *et al.*, 2020a; 2020b; Harrak, 2021).

Figure 1. Some cactus-based products developed by INRA - CRRA Marrakech: a) Fruit and cladode juices; b) Peel powder from yellow and red fruits (CRRA, 2018).

Valorization of food legumes

Food legumes and climate resilience

Pulse upgrading is a key area in the transition to more resilient agricultural systems in the face of different challenges. Alongside the socio-economic interest, legumes grown in arid areas play an important agronomic and environmental role in improving soil health and contributing to the mitigation and adaptation of agricultural production systems to the effects of climate change (Martín-Cabrejas, 2019). In addition, from a nutritional and dietary point of view, legumes are an important source of plant protein, dietary fiber, and nutrients. Incorporating these products into meals helps prevent various forms of malnutrition (Hughes *et al.*, 2022). However, this sector is struggling to reach its potential since legumes are generally sold at a very low level of valorization (fresh or dry grains) and traditional. Hence the interest in focusing more on the valorization of legumes through the reduction of post-harvest losses and the diversification of nutritious by-products to improve their access and availability.

Characterization of food legumes

Legumes are generally characterized by a high protein content (20 % - 35 %) compared to cereals and are rich in lysine and sulfur amino acids such as methionine which are limited in most plant foods. In addition, legumes provide bioactive compounds that contribute to reducing the risks of cardiovascular disease, diabetes, and certain types of cancer (Monnet *et al.*, 2019).

The research and development works carried out at INRA (CRRA Meknes) have led to the development of a range of twenty-two legume-based products from several genotypes selected by INRA for their typicity and their nutritional and technological characteristics (INRA, 2019).

Couscous based on durum wheat reinforced with legumes (bean, chickpea, and lentil) at 30 % and 50 % showed, compared to basic couscous (100 % durum wheat), a significantly lower water activity and less bacterial contamination and consequently, a longer shelf life. In addition, based on ash, protein, and dietary fiber contents, the nutritional quality of reinforced couscous with legumes is better (Guirrou *et al.*, 2022).

Development of preservation and transformation processes

The products developed by INRA (CRRA Meknes) concern canned food and processed products (flours, ready-cooked dishes, couscous, and Moroccan cakes). The canned foods, without the addition of preservatives or additives, can be competitive with similar imported products and deserve to be labelled under SDOQ as local products prepared with Moroccan legumes varieties adapted to each region. The flours developed from legumes (chickpeas, beans, and lentils) could be proposed as an alternative to gluten-free products and food additives to improve the texture of products by giving them a denser, fluffy, or crispy consistency (Bouhlal *et al.*, 2019; Benali *et al.*, 2021; Benayad *et al.*, 2021).

In addition, innovative products are designed in the form of ready-cooked dishes to remedy disadvantages that reduce the consumption of legumes, despite their good nutritional quality. These disadvantages include problems with digestion (bloating and flatulence), long cooking time, presence of anti-nutrients that affect the absorption capacity of proteins, amino acids, and minerals, and changes in eating habits including the trend towards ready-cooked dishes (including fast food) (Figueira *et al.*, 2019; Bielefeld *et al.*, 2021). Furthermore, the design of these ready-cooked dishes has made it possible, using improved traditional cooking methods, to obtain innovative products without recourse to preservatives, thus preserving a typical Moroccan taste (Fig. 2).

Figure 2. Innovative ready-cooked dishes developed by INRA - CRRA Meknes for the benefit of cooperatives: a) Bissara; b) Laâdas; c) Loubia; d) Moroccan Hamous.

A range of wheat-based couscous reinforced with legumes was also developed. Indeed, the combination of legumes with cereals allows our body to have essential amino acids including lysine and methionine. It also makes it possible to strengthen the content of fiber, minerals, and vitamins of the B group, increasing the rate of protein assimilation by 30 % to 50 % (Monnet *et al.*, 2019). This range of couscous has the particularity of being developed based on the wheat-legume combination. Similar products existing on the Moroccan market are made of a mixture of cereals (wheat, barley, millet, etc.) with or without rice.

The recipe of Moroccan cakes, known as Fekkas, were innovated by preparing them from a mixture of equal amounts of wheat and legumes (beans, chickpeas, or lentils). They are proposed to be either salty or sweet, to target a broad category of consumers.

Valorization of olive oils

Olive tree and climate resilience

The olive sector is of great socio-economic importance at the national level and is one of the priority sectors of the GG strategy. It has two particularities: the 90 % dominance of the olive-growing heritage by the population variety "Picholine marocaine" and its wide distribution on different bioclimatic levels from the north to the south of Morocco (MAPMDREF, 2023b). The olive tree is a hardy genotype that is one of the best models for adapting to climate change. The existence of century-old trees in several terroirs is a testimony to both the anchoring of olive cultivation and its great adaptation to climate change. Moreover, the determination of the typicity of the national olive-growing heritage has highlighted its true potential as a source of biodiversity and varietal selection, thus requiring its conservation and protection. For this, the protection of several specific olive terroirs under SDOQ has been consolidated in the PMV and GG strategies (MAPMDREF, 2023a).

Characterization of olive oil quality and typicity

Olive oil is faced with regulations dictated by health and environmental issues in a context of globalization and standardization of international standards. Through these aspects, quality has become an important field of challenges to positioning the sector on regional, national, or international markets. In this context, the major current challenges lie on the one hand, in the compliance of olive oils produced and marketed with the composition, quality and purity criteria provided by the standards in force; and on the other hand, in overcoming the factors that handicap the promotion of quality, in particular the lack of information and consumer awareness.

Indeed, it is noted that genotype factors and climate change in several major olive basins, particularly in the South, have generated high values of concern, which can reach an average of 1.30 %, compared to the International Olive Council (IOC) standard for the upper limit set at less than or equal to 1.00 % of C18:3 linolenic acid (IOC, 2022). This exceedance of the content of this fatty acid has also been recorded in the northern olive-growing basins because of global warming (El-Antari *et al.*, 2019). For this purpose, INRA contribution to the research work within the framework of IOC expert committees resulted in the adoption of a specific decision tree for this fatty acid within a range of 1.00 % ≤ C18:3 ≤ 1.40 % provided that the apparent β-sitosterol / campesterol ratio is ≥ 24 and that all other composition factors are within official limit (IOC, 2022). This proposal is undergoing validation by the *Codex Alimentarius*.

In terms of organoleptic performance, Picholine marocaine is characterized by an average fruitiness, a balanced average bitter and pungent taste as well as specific aromas generally represented by tomato, artichoke, and green almond. However, in some potential sites, intense fruitiness and variable specific aromas are noted with very interesting complexity and harmony (Fig. 3).

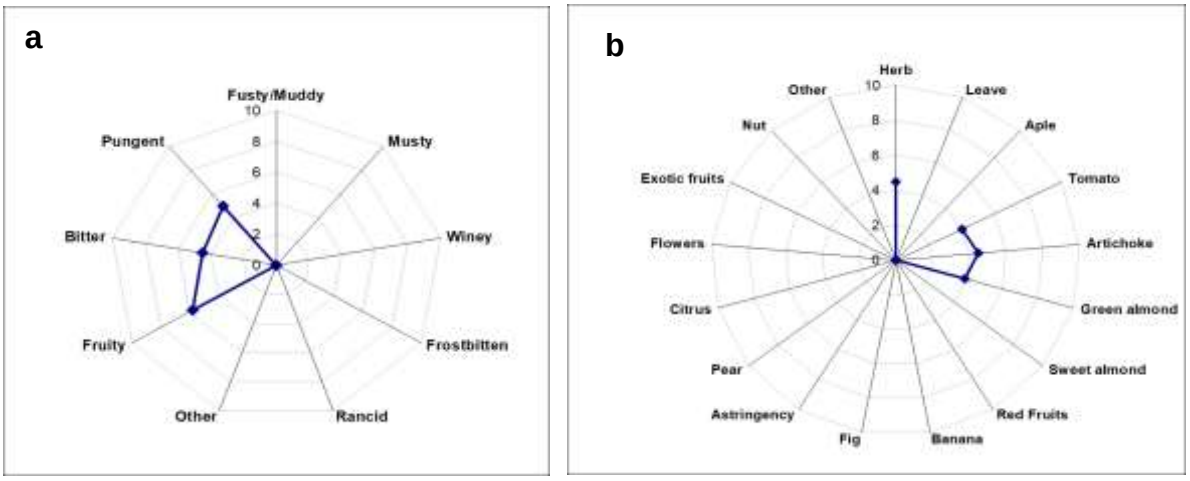

Figure 3. Typical sensory profile of olive oils of the Moroccan Picholine variety: a) Positive attributes; b) Specific aromas.

In the multidisciplinary process of varietal selection, the evaluation of the technological performance and typicity of the genotypes preselected by INRA integrates quality and purity characterization, organoleptic performance as well as consumer acceptability of their olive oils. The result of this work has contributed to the selection of efficient varieties adapted to local conditions for the diversification and strengthening of the Moroccan olive heritage (Menara, Haouzia, Tassaout, Dalia, Mechkate, and Agdal). Haouzia, Tassaout, and Dalia varieties were awarded gold medals in the Olea Mogador (2023 edition) provincial olive oil competition in Essaouira. The contribution of INRA (CRRA Marrakech) is also notable in highlighting the performance of indigenous varieties (Bouchouika, Bouchouk Laghlid, Berri Meslal, and Bakhbouch Beldi) (Boukachabine *et al.*, 2011). Following their great adaptation to the pedoclimatic conditions of their terroirs, these native varieties have very interesting phenotypic performances in terms of productivity and quality. However, the moroccan Picholine characterized by a wide plasticity by being present in all Moroccan olive-growing basins, remains an exploitation mine for the selection of other efficient varieties adapted to climate change (El-Antari and Sikaoui, 2022).

Development of distinctive signs of origin and quality

In the national agricultural strategies, particular attention was paid to the establishment and recognition of food products SDOQ in general and olive oil in particular. The first protected denomination of origin (DOP) developed in Morocco with the assistance of INRA and recognized by the Ministry of Agriculture, Fishries, Rural Developement, Water and Forests (MAPMDREF) in 2009, is that of Tyout Chiadma olive oil. Currently, there are 16 olive oil SDOQ, the majority of which are developed with the scientific and technical contribution of INRA, thus translating the protection of 16 well-known olive terroirs. These terroirs are holders of a plant material resilient to climate change and offering specific olive oils with a richness in phenolic compounds and a great potential for quality and stability. In addition, these terroirs are distinguished by the presence of certain high-performance centenary specimens following their adaptation to different climatic conditions, both mild/clement and severe. The role of research is essential in the identification and preservation of biodiversity and notoriety of terroirs under SDOQ. Moreover, the effective involvement of the local population is essential to promote and preserve this biodiversity as well as the typicity of the olive oils of these terroirs, in accordance with the protocols and international standards in force.

Valorization of aromatic and medicinal plants

Aromatic and medicinal plants and climate resilience

Aromatic and medicinal plants (AMP) play a significant role in enhancing resilience to climate change. They are distinguished by their high capacity to adapt to high temperatures, drought, and other environmental stresses. Their natural resilience can help maintain agricultural productivity and ensure the availability of food resources, even in challenging climatic conditions (Kikon and Angami, 2018). The post-harvest valorization of AMP can significantly contribute to enhancing resilience to climate change. By cultivating these plants, farmers can diversify their income sources and reduce their dependence on traditional crops that may be more vulnerable to the impacts of climate change.

Characterization of AMP quality

AMP possess a considerable advantage due to the progressive discovery of applications of their essential oils (EO) characterized by anti-inflammatory, antiseptic, antiviral,

antifungal, bactericidal, and detoxifying properties. Their numerous uses contribute to an increasing demand for them in global markets (Bengyella *et al.*, 2011).

To contribute to the valorization of the national heritage of AMP, several research efforts have focused on the chemical composition and on major active compounds, as well as their biological properties. The impact of the harvesting period and the processing method of these AMP on EO yields, major active compounds, and their biological properties (especially antibacterial and antioxidant activities) has been studied (Zantar *et al.*, 2015). EO yields are influenced by the harvest period, storage, drying, and processing methods of AMP. The best yields are generally obtained during the full flowering stage of plants. Therefore, it appears opportune to control the harvesting period of AMP to optimize essential oil production and to obtain maximum yield per plant. The average yields and physicochemical characteristics of essential oils from the main AMP are illustrated in Table 2 (Zantar, 2018).

Table 2. Yields and physicochemical characteristics of essential oils from some aromatic and medicinal plants of Northern Morocco (Zantar, 2018).

Aromatic and medicinal plant	Yield (%)	Acid index (mg KOH/g)	Refractive index	Polarization rotation ($°.g^{-1}.dm^{-1}.cm^{3}$)
Thymus vulgaris	2.10 ± 0.09	4.00 ± 0.10	1.50 ± 0.02	-4.00 ± 0.20
Salvia officinalis	1.40 ± 0.08	3.33 ± 0.20	1.46 ± 0.04	+26.50 ± 0.90
Thymus satureioides	4.70 ± 0.12	1.12 ± 0.02	1.49 ± 0.05	-6.00 ± 0.20
Laurus nobilis	0.67 ± 0.15	0.96 ± 0.04	1.47 ± 0.08	-21.60 ± 2.60
Rosmarinus officinalis	1.95 ± 0.14	2.24 ± 0.09	1.46 ± 0.12	-1.30 ± 0.03

The analysis of EO chemical composition showed that the major constituents were thymol (60.70 % to 63.92 %) for *Thymus vulgaris*, (E)-β-ocimene (23.92 % to 26.13 %) for *Salvia officinalis*, carvacrol (52.37 % to 54.20 %) for *Thymus satureioides*, 1,8-cineole (40.65 % to 41.32 %) for *Rosmarinus officinalis*, and 1,8-cineole (42.00 % to 44.00 %) for *Laurus nobilis* (Zantar, 2014).

Furthermore, the assessment of antioxidant activities of EO has revealed that they are influenced by both the harvesting stage and the preparation method of the plant material for EO extraction. Indeed, the full flowering stage is the optimal period for the harvest of *Thymus vulgaris*, resulting in an antioxidant activity of 88.24 %, higher than that recorded during pre-flowering (86.29 %). This difference is linked to the proportion of phenolic compounds present, particularly thymol, which exhibits a significant increase during full flowering (Zantar *et al.*, 2015).

The EO of ground *Salvia officinalis* exhibited higher antioxidant activity compared to that of unground *Salvia officinalis* (77.05 % and 71.42 %, respectively). Grinding promoted the extraction of active compounds, particularly increasing the content of (E)-β-ocimene from 23.92 % to 26.13 % (Zantar, 2018).

Development of AMP preservation processes

Traditional drying of AMP was the most used method by cooperatives. It allows us to preserve the AMP quality in a simple and natural manner. However, this type of drying has disadvantages such as contamination of plant material by molds and a relatively long and uncontrolled drying time. To optimize drying conditions, several research studies have been conducted by the INRA (CRRA Tangier). EO yield, chemical composition, antioxidant activity, and antibacterial activity are affected by the duration and temperature of drying. The optimal drying parameters, which have better results in terms of yield, chemical composition, color, antibacterial activity, and antioxidant activity, are summarized in Table 3.

Table 3. Recommended temperatures and durations for drying the main aromatic and medicinal plants of Northern Morocco (Zantar, 2018).

Plants	Temperature / Drying duration	Quality evaluation criterion
Thymys satureioide	30 °C for 4 days or room temperature in the shade for 8 days	Y/CC/ABA/AA
Thymus vulgaris	30 °C for 4 days or ambient temperature in the shade for 12 days	Y/CC/ABA/AA
Origanum onites	30 °C for 6 days or room temperature in the shade for 8 days	Y/CC/ABA/AA
Origanum vulgare	30 °C for 6 days or ambient temperature in the shade for 10 days	Y/CC/ABA/AA
Salvia officinalis	40 °C for 6 days	Y/CC/ABA/AA
Origanum majorana	Room temperature in the shade for 8 days	Y/CC/ABA/AA
Satureja montana	Room temperature in the shade for 12 days	Y/CC/ABA/AA

Yield (Y); Antibacterial Activity (ABA); Antioxidant Activity (AA); Chemical Composition (CC).

AMP valorization as natural preservatives and flavorings

The use of chemical preservatives in food preservation is becoming increasingly unacceptable due to their negative impacts on human health. The use of natural substances as bio-preservatives is currently more appreciated by consumers (Vivek *et al.*, 2011). The effect of incorporating EO of *Thymus vulgaris* and *Origanum compactum* at concentrations of 0.05 % and 0.1 % on the sensory, physicochemical, and microbiological characteristics of fresh goat cheese stored at 8 °C was studied. No significant difference was observed between the control cheese and the flavored cheeses regarding pH, titratable acidity, dry matter, lactic acid bacteria, and total aerobic mesophilic flora. However, coliforms were completely inhibited by the action of these two essential oils from the first day of storage. The incorporation of *Origanum compactum* essential oil into fresh goat cheese is more effective in extending shelf life than that of *Thymus vulgaris* (Zantar *et al.*, 2014). These results confirm the importance of AMP and EO as resilient bio-preservatives, enabling a reduction in waste and a rational energy use for preservation purposes.

Date valorization

Date palm and climatic resilience

The date palm (*Phœnix dactylifera* L.) is one of the rare food crops adapted to extreme climatic conditions (drought, salinity, high heat, etc.). In Morocco, the date palm sector ensured an average production of 140,000 tons (between 2020 and 2022), occupying thus the first place among the production sectors in the oasis areas and contributing from 20 % to 60 % of farmers income (Noutfia *et al.*, 2023). Despite this dynamic, the Moroccan date remains faced to several constraints, including the poor mastery of technological processes linked to its valorization. Below are some sustainable models guaranteeing the resilience of the downstream of date palm sector.

Cold storage of dates

The appropriate preservation and storage of dates is an essential solution to ensure the availability of this fruit on the market for long periods while preserving its intrinsic and extrinsic qualities (Noutfia *et al.*, 2019). The association of "the resilience" dimension with "the good preservation and storage of dates" implies the suggestion of a conservation scheme to the actors downstream of the sector. This scheme should be adapted to the typicity of the oasis context, to the specificity of Moroccan dates and to their cold storage infrastructures. The scheme suggested by INRA is based on three pillars:

Pillar 1: *Choice of the optimal maturity stage for dates harvesting*

Dates intended for storage/warehousing should, in general, be harvested at an advanced stage of maturity (Tamar stage) which gives dates the best organoleptic, technological and preservation potential (Fig. 4).

Figure 4. Illustration from right to left of the three main stages of date maturity (Khalal, Routab, and Tamar).

Pillar 2: *Optimization of the cold storage process*

At the date storage facilities, it is recommended to carry out the following treatments: sorting, fumigation, hydration/drying, packaging, to preserve the quality of the dates until they are shipped/leased to the markets. Fumigation must be applied according to current standards and the use of phosphine as an active substance for treating dates is widely recommended. The hydration or drying of dates must be carried out according to the consistency and the wet fraction, with the aim of reducing the suggested water content to around 20 %.

Pillar 3: *Mastery of date preservation scales*

Cold storage and warehousing of dates take place generally in cold rooms with a unit capacity of one ton (Noutfia *et al.*, 2018). The two parameters having a direct impact on the quality of dates are temperature and relative humidity. Table 4 reported scales for adequate conservation according to the category of dates (Noutfia, 2021).

Table 4. Scales proposed for the preservation of soft, semi-soft, and dry dates for a period of more than 3 months (Noutfia, 2021).

Parameter	Dried dates	Semi-soft dates	Soft dates
Temperature	< 25 °C or ambient temperature	0 °C - 4 °C	0 °C - 2 °C
Relative Humidity	-	60 % - 70 %	75 % - 80 %

Freezing between –18 °C and –25 °C (without controlling relative humidity) is recommended for preservation of dates, especially those of soft consistency (Misbah *et al.*, 2022).

Characterization of dates typicity and quality

The nutritional, technological, organoleptic, and commercial qualities of dates from more than thirty of the main Moroccan varieties were studied through the determination of several physical, physicochemical, biochemical, and sensory parameters (pulp content, humidity, Brix, water activity, pH, total titratable acidity, proteins, phenolic compounds, ash, minerals, aroma compounds, flavor, texture, etc.). This expertise in the field of highlighting the quality of dates allowed INRA to be asked to contribute to the development of SDOQ and to the process of establishing national and international date standards, in particular the *Codex Alimentarius* standards (Harrak, 2020; 2022).

Development of date SDOQ

The research findings of INRA (CRRA Marrakech) have contributed to the development of the protected geographical indications (IGP) Bouittob Dates of Tata, IGP Outoukdim Dates of Toudgha Tinghir, and IGP Black Bousthammi Dates of Drâa. These SDOQ allow the protection, valorization, and recognition of the historical anchoring of these dates in their respective terroirs (Fig. 5). CRRA Marrakech also contributed to the development of the code of practices for the IGP Jihel Dates of Drâa and the agricultural label (LA) Najda Dates, and to the improvement of the code of practices for the IGP Assiane Dates of Figuig (Harrak, 2020; 2022).

Figure 5. Protected geographical indications: a) Bouittob dates of from Tata; b) Outoukdim dates of Toudgha Tinghir; c) Black Bousthammi dates of Drâa (Harrak, 2022).

Contribution to the archiving of traditional date processing know-how

Oasis women have ancestral know-how in processing dates into various locally appreciated products: juice, syrup, vinegar, paste, powder, etc. However, the transmission of this traditional know-how from generation to generation has declined significantly and the valorization of these local products remains insufficient. In order to safeguard this know-how, INRA (CRRA Marrakech) has listed more than thirty traditional date-based preparations. These preparations are often associated with AMP which give them flavoring, preservation, and medicinal properties. These traditional date products can be considered as local or terroir products and deserve to be promoted. Two products have been identified as promising products to be promoted based on their organoleptic qualities and therapeutic virtues: Tassabount (or Toummit) date paste and Tassabount (or Takachoult) date juice. It should be noted that these two products bear the same local name Tassabount which refers for the juice to its foamy character and for the paste to its appearance reminiscent of soap (Harrak, 2018; 2022; Harrak *et al.*, 2018).

Development and adaptation of date transformation processes

For better valorization of low and medium commercial quality dates also integrating dates eliminated during the sorting operation in the packaging units, research work on the transformation of dates has made it possible to develop and adapt processes of jams, marmalades, powders, pastes, etc. These products, characterized by good nutritional, organoleptic, and commercial qualities, can be consumed directly or incorporated into other food preparations (Harrak, 2019). With the tendency of dates to dry out because of climate change, their processing into powder remains an appropriate route for their valorization as in the case of dates of Ademou, Bouskri, and Bouijjou varieties which have a high aptitude for processing into powder.

Carob tree valorization

Carob and climate resilience

The carob great hardiness, low cultivation requirements and processing and marketing potential have made it an excellent resilience alternative for arid and semi-arid zones. To this end, the agricultural development program of the Moroccan government has targeted an increase in carob plantation area to 100,000 hectares by 2030 (MAPMDREF, 2023b).

Moreover, although Morocco is the second largest producer of pods and leading exporter of seeds in the world, the development of the carob sector faces several constraints, particularly in terms of valorization. In fact, the sector is dominated by bulk sales of crushed pods and seeds. Thus, for greater profitability and in the face of increased demand for carob products, processing is essential to further enhance the resilience and competitiveness of the sector (Elfazazi, 2017; MAPMDREF, 2023b).

Characterization of carob quality

The composition of the pod is very diverse, both in terms of pulp and seeds. The pulp represents 70 % to 90 % of the pod. It is rich in sugars (40 % - 60 %) mainly saccharose and glucose, phenolic compounds, particularly tannins (18 % - 20 %), dietary fiber (27 % - 50 %) and minerals (potassium, sodium, iron, copper, manganese, and zinc). It contains small amounts of protein (3 % - 7 %) and lipids (0.4 % - 0.8 %) (Elfazazi, 2017; Yatim *et al.*, 2022). Seeds represent from 10 % to 30 % of the pod. They consist of a tegument (30 % - 33 %), the endosperm (42 % - 46 %), and the germ (23 % - 25 %). The germ is rich in protein (55 % - 65 %). The endosperm contains a high percentage of galactomannan (a polysaccharide composed of mannose and galactose) (80 % - 85 %). This percentage determines the commercial value of the carob seed. Carob gum made from pure galactomannan is used as a food additive known by the acronym E410 (Elbatal, 2014; Laaraj *et al.*, 2023; Moumou *et al.*, 2023).

Development of carob transformation processes

Carob pulp has a high processing potential. The products developed from this pulp by INRA (CRRA Tadla) are mainly torrified powder, beverages, syrup, vinegar, carob spread, and an animal feed formulation (Fig. 6). Pulp powder is naturally free of caffeine and theobromine, unlike cocoa, which contains relatively high quantities of these anti-nutritional components. It is therefore widely used as a substitute for cocoa in the formulation of a wide range of food products (Elfazazi, 2017). Beverages are prepared from crushed carob or pulp powder using a diffusion process that ensures optimal extraction of carob nutritive constituents. They are offered without added sugars and flavored with cinnamon and/or licorice (Elfazazi *et al.*, 2020).

Syrup is a nutritious food containing high quantities of natural sugars, mineral elements, organic acids and bioactive compounds (Elbatal, 2014; INRA, 2018). Vinegar is a product derived from the fermentation of carob pulp offering a long shelf life (over 5 years). The spread is an innovative product. Its formula and manufacturing process are protected by patent no. 60436, deposited in 2023. It is a product of high nutritional and organoleptic quality, thermally stabilized with no added conservatives. The pulp is also used as a complement in the formulation of compound feeds for livestock. The incorporation of controlled portions in sheep feed has a remarkable effect on fattening, production performance, and meat quality (Benbati *et al.*, 2021).

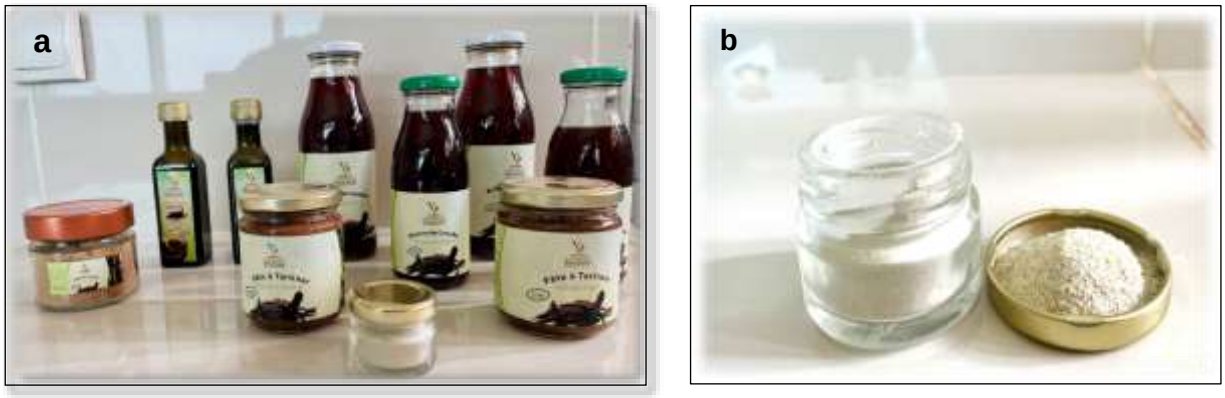

Figure 6. Carob-based products developed by INRA - CRRA Tadla: a) Powder, syrup, beverages, vinegar, carob paste; b) Carob gum.

Regarding seed transformation into pure gum (E410), the extraction process has been improved by optimizing the thermomechanical and chemical methods used, to exploit its stabilizing and thickening properties in food, pharmaceutical, cosmetic, textile, and other industries (Laaraj *et al.,* 2023) (Fig. 6).

Carob leaves are an important source of sugars, minerals, antioxidants, antibacterial and anticarcinogenic substances. Research has revealed their potential exploitation in the agri-food, medical, and pharmaceutical fields (Elbouzidi *et al.*, 2023; Laaraj *et al.*, 2024).

Development of Carob SDOQ

The valorization of the carob tree through the SDOQ will enable better marketing and promotion of Moroccan carob, considering its high quality and typicity within several geographical areas. Research work by INRA (CRRA Tadla) on the typical characteristics of carob produced in the Beni Mellal - Khenifra region has contributed to the development of specifications for the Kharoub Azilal PGI, whose recognition process is currently ongoing (Elfazazi, 2017; Elfazazi *et al.*, 2017; Elfazazi *et al.*, 2020).

Technology transfer and capacity-building

The actions to capitalize on INRA research achievements related to the post-harvest valorization of resilient local products were implemented through a combination of theoretical and hands-on training, dissemination of mature technologies, and technical assistance as part of the solidarity transfer and capacity building initiatives for development agencies and professional organizations.

Prospects for strengthening the resilience of local products

Moroccan local products are perfectly suitable for the development of specific areas in arid and semi-arid regions. They have numerous ecological, socio-economic, technological, and industrial potentialities. Their notoriety, typicity and quality are well established. To support the value chains of these local products and enhance their resilient traits

and potential, a range of several transversal orientations and actions are essential:

- Encouragement of investors, young entrepreneurs and professional groups for setting up a modern agro-industry allowing the establishment of judicious actions for the valorization and promotion of these products in accordance with the national strategy GG 2020-2030.
- Establishing valorization centers in the regions where these local products are produced, aiming to enriching the local communities through the generated added value.
- Raise consumer awareness of the nutritional and functional benefits of local products.
- Supporting scientific research and development programs to ensure effective and sustainable synergy between the upstream and downstream value chains of these local products.

In this context, INRA strategic research orientations in the field of agri-food technology, in line with scientific advances, are among the development priorities of the various sectors at the regional and national levels. These research orientations also play a key role in the emergence of resilient food systems by preserving biodiversity and traditional knowledge, supporting local sourcing, and strengthening social and community ties. They thus contribute to developing local products capable of facing the challenges of global change while preserving and promoting local heritage. Prospective research will be oriented more towards consolidating INRA expertise in the areas of valorization and promotion of resilient local products. INRA involvement will be strengthened to understand any possible influence of global changes on the nutritional, nutraceutical and/or therapeutic potential of these products, through:

- Identification and characterization of nutritional and bioactive compounds and study of their variation according to environmental conditions.
- Innovative research for a better positioning in the market while preserving their notoriety, increasing their added value and guaranteeing their sustainability.

Conflicts of interest

The authors have no conflicts of interest to declare.

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