Chapter

Adaptation Strategies and Microwave Drying of Amaranth Species with a High Nutritional Value to the Ecuadorian Andean Region

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Abstract

In the Andean region of Ecuador, amaranth is a key species not only for its high nutritional value but also for its association with Ecuadorian culture, since it is one of the main indigenous crops of the pre-Columbian era. Over the time, the cultivation of this species ceased for several reasons result. However, in recent years, a number of strategies have been developed to retrieve it on a national level. In accordance with these strategies, the "Amaranth Improvement Program for Cotopaxi" (PROMAC) is being developed at the Technical University of Cotopaxi, with the main objective of selecting varieties with high levels of biologically active substances. This program is been executed through two main lines of investigation: (a) selection of varieties of amaranth of high nutritional value and (b) the improvement of techniques for conservation of the seeds. This chapter analyzes and shows the main results obtained to date from the study of eight varieties of amaranth seeds and the drying of one of the seeds by means of microwave energy in order to improve its conservation. In the light of the results obtained, the strategies to develop the following research lines within the PROMAC framework are exposed.

Keywords: amaranth, *Amaranthus* spp., adaptive response, microwave drying, conservation strategies, post-harvest techniques

1. Introduction

Amaranth is a crop of America, whose origin and exploitation probably dates back to between 4000 and 5000 BC. According to [1, 2], the first evidence of domestication is located in Central America (Guatemala and Mexico) and South America (Ecuador, Peru and Bolivia). Known as *huauhtli*, it refers to the amaranth species *A. hipochondriacus* L., a pseudocereal which for those tribes had a sociocultural and economic significance. Its value was as great as that of corn and beans, the traditional crops of these people.

It should be noted however that according to several chronicles, the term *huauhtli* was used not only to refer to amaranth (*Amaranthus*) but also to quenopodios (*Chenopodium*).

The American origin of several *Amaranthus* species, employed nowadays for the production of grain, has been confirmed by several archeological studies. Amaranth was used even before the beginning of domestication [3]. In particular, the excavations carried out by MacNeish (1964) yielded some very interesting data about the crop. Amaranth seeds were found in their excavations, as a result of which they concluded that this crop was grown during the Coxacatlán period (5000–3400 years BC), which means that the domestication of amaranth occurred at the same time as that of corn.

On the basis of these data, it is clear that the amaranth was a crop widely used by the Aztecs and their neighbors [3]. Under the empire of Moctezuma II, amaranth seeds were highly valued, first as one of the main crops in people's diet, and second because amaranth seeds were used to make figures of Aztec idols [4]. They were also used in religious ceremonies among the ancient Mexicans, in honor of the Aztec god of the sun and war "*Huitzilopochtli*" and the god of rain "*Tlaloc*" [5]. It is widely believed that, because of its use in religious ceremonies, this crop was considered as a symbol of paganism after the Spanish conquest, and its cultivation was consequently prohibited. However, no conclusive evidence has been found of the gradual disappearance and prohibition of amaranth cultivation as a result of Spanish conquest [4].

The first species cultivated in the pre-Columbian era to obtain grain were: *A. hypochondriacus* L. in Mexico, *A. caudatus* L. in the Andean region, and *A. cruentus* L. over a wide area of Central America [3, 5]. The introduction of the first amaranth plants to Europe occurred during the colonial era, when they were used as ornamental plants. The seeds employed for the production of amaranth were the black variety. However, samples of the white *A. hypochondriacus* L. seed that date from the sixteenth century were also found [3]. This indicates that *Amaranthus* seeds came to Europe in the form of two varieties (black and white), though black seeds were the most commonly used.

The dispersion of amaranth seeds to other continents may have occurred through commercial traffic from Europe to other regions of the world, such as Asia. In this region, particularly in Sri Lanka (known initially as Ceylon) and in India, there are traces of crops whose records date back to the eighteenth century. It is believed that the seeds were introduced by the Dutch. In the first half of the nineteenth century, the crop expanded across the Deccan plain in South India and the Himalayas. It is also known that in the nineteenth century, its cultivation began in China and eastern Siberia [3].

Currently, amaranth is considered one of the most promising crops for combating malnutrition in this century [6, 7] for several reasons: first, because of its adaptability to unfavorable environmental conditions [8], second because its cultivation does not demand much water and its agronomic management does not require much care, making its production cheaper compared with other similar crops [9], and finally, because of its high nutraceutical value [6, 10].

Amaranth is a rich source of protein [6, 7, 10, 11], vitamins, fiber, and calcium [1–3, 6, 7, 10]. Consequently, it is used as a food (mainly the leaves and the seeds), but also as an additional protein supplement for livestock. Moreover, it is used in medicine because of anti-inflammatory, hemostatic, and diuretic properties [6, 7]. And more recently, the flour of amaranth has attracted the attention of industry because of its chemical composition and nutritional value [7, 12]. For these reasons, the interest of researchers and cultivators in amaranth seeds has increased considerably in recent years [7].

In Ecuador, this crop is known as Ataco, Sangorache or Quinua de Castilla and is used mainly as fodder. Several species can be found: *A. blitum* L. and *A. hybridus* L., also known as bledos. In the Costa region, *A. dubius* Mart. ex Thell. has also been found [13]. However, the species that are most commonly used as crops are: *A. quitensis* Kunth or *A. hybridus* L.

As a means to recover this crop, the National Program of Legumes and Andean Grains was created in 1982. An important part of the plan was to collect amaranth seeds over an extensive area of approximately 1000 km in the inter-Andean alley. A total of 114 samples were registered up to the year 1985, most of which belonged to the *A. hybridus* species. [14].

Subsequently, a knowledge exchange program between different institutions involved in the development of the amaranth crop was introduced. As a result of this, the species *Amaranthus cruentus* L.—the INIAP Alegría variety, obtained from the"Alan García" variety, was introduced from the University of San Antonio Abad in Cusco, Peru.

Before being introduced, this variety had passed a previous selection process in the National Institute of Agricultural Research (INIAP), in the years 1987 and 1988.

The INIAP Alegría variety was released to farmers in 1994 [1] after several years of research into its management, adaptability, and grain processing among other aspects.

Currently, in Ecuador, the cultivation of the ancient crops quinoa (*Chenopodium quinoa* Will.), Lupinus (*Lupinus mutabilis* L.), and amaranth (*Amaranthus* spp.) is experiencing a rate of very high growth. Of these crops, the one in greatest demand for export is quinoa. However, amaranth is also in high demand in the United States, where NASA is carrying out research into the potential of amaranth as a source of nutrition for astronauts [15].

Despite the growing interest in this crop and its enormous potential, more research is required regarding crop management, adaptation strategies, and post-harvest techniques in order for this crop to be considered as a main source of food in Ecuador.

2. Program for improvement and selection of amaranth in Cotopaxi (PROMAC)

For the reasons explained above, various programs have been introduced in Ecuador to adapt and improve amaranth crops. One of these programs is the *Program for Improvement and Selection of Amaranth in Cotopaxi (PROMAC)* the main objective of which is to develop and implement strategies for adapting amaranth species to the conditions of the province.

The program arises from the need to incorporate new promising lines of research that will amaranth crops to be reintroduced into the province of Cotopaxi. The work has been developed mainly at the Technical University of Cotopaxi in Latacunga and has been carried out in collaboration with the Russian Federal Center for Scientific Research in Vegetables (VNIISSOK) and the Russian University of Friendship of Peoples (RUDN).

This program has followed two strategic lines of research:

The first line has the aim of selecting varieties of amaranth of high nutritional value to be adapted to the Andean region, while the second line aims to improve the techniques used to conserve the seeds, since in the case of Cotopaxi, seed conservation is one of the least efficient processes and is the cause of the high loss of seeds that seriously affects the crop yield. This program began in early 2016 and is still ongoing.

A summary of the progress made to date of the two lines of investigation mentioned above is presented below.

3. Selection of varieties with a high nutritional value

This work is partly based on the research previously carried out in The Federal Center for Scientific Research on Vegetables (VNIISSOK) of Russia which has one of the highest number of amaranth seed collections of the Russian Federation.

As part of the project carried out in this institution, 10 varieties were released for production in the central zone of Moscow and some areas of Southern Russia [16].

The objective planned within the framework of the PROMAC was to ascertain whether the varieties previously studied in Russia could be adapted to the conditions of Cotopaxi. This study was incorporated as part of two degree courses [17, 18].

3.1 Material employed and variables analyzed

The study of the adaptability of amaranth in Cotopaxi began with the characterization of different samples from the All Russian Research Institute N.I. Vavilov.

Table 1 shows the samples selected, with references to their origin and the corresponding species.

As can be seen in **Table 1**, there are some collections of samples that were not identified in their storage origin due basically because they share intermediate morphological characters with close relatives. The identification of the remaining species is considered in a second phase of the program (PROMAC) based on morphological, biochemical, and genetic markers.

Each of the collections was planted, in different experimental units. For this purpose, 8.3 m^2 plots were designed.

Then, different biometric and physiological indicators were measured according to the recommendations of Mujica [19] and Torres [20].

The color of the seeds, stem length, inflorescence length, and the number of leaves at the time of harvesting were employed as biometric indicators. Data were obtained from 10 plants in each plot. Likewise, after harvesting, the average weight of 1000 seeds was calculated.

Origin	Collection number	Species
Belgium	VIR NN	*A. caudatus*
Belgium	VIR 666	*A. cruentus*
France	VIR 686	*A. cruentus*
United States	VIR 796	*Amaranthus* sp.
Mongolia	VIR 690	*A. hybridus*
Argentina	VIR 674	*A. hypochondriacus*
Mexico	VIR 584	*Amaranthus* sp.
China	VIR 711	*Amaranthus* sp.

VIR identify code number for the All Russian Research Institute N.I. Vavilov.
NN, No number assigned.

Table 1.
Species employed in the study.

Time to emergence	Scale	Classification
Less than 10 days	1	Short-term
From 11 to 15 days	2	Medium-term
More than 16 days	3	Long-term

Table 2.
Seed emergence time scales according to [20].

The physiological indicators used were: the number of days for seeds to emerge, the number of days for a milky grain and for a dry grain, and the number of days for physiological maturation.

The number of days for the seeds to emerge was measured in the seedbed. The time at which 70–80% of seeds germinated was recorded and classified according to the scale shown in **Table 2**.

In order to corroborate the relation between the variables analyzed, a Pearson's correlation coefficient analysis was performed, in combination with a conglomerate analysis to group the species studied.

3.2 Biometric and physiological differences between the species studied

The adaptability tests for the eight varieties studied were successful, although some differences between the different species were found depending on the variables analyzed.

Based on the data recorded, the following results were obtained:

The color of the seeds recorded at the time of harvest revealed four specimens of white seed (of different shades), three collections of black seed, and one collection of brown seeds, as shown in **Figure 1**.

The results of the analysis of the morphological variables: stem length, inflorescence length, and the number of leaves are shown in **Figure 2**.

The stem lengths, ranged between 23 cm for *Amaranthus* sp. (originating in China) and 130 cm for *Amaranthus cruentus*, originally from Belgium.

The size of the panicle (inflorescence length) oscillated between 17 cm on average for the species *Amaranthus cruentus*, originally from Belgium and the

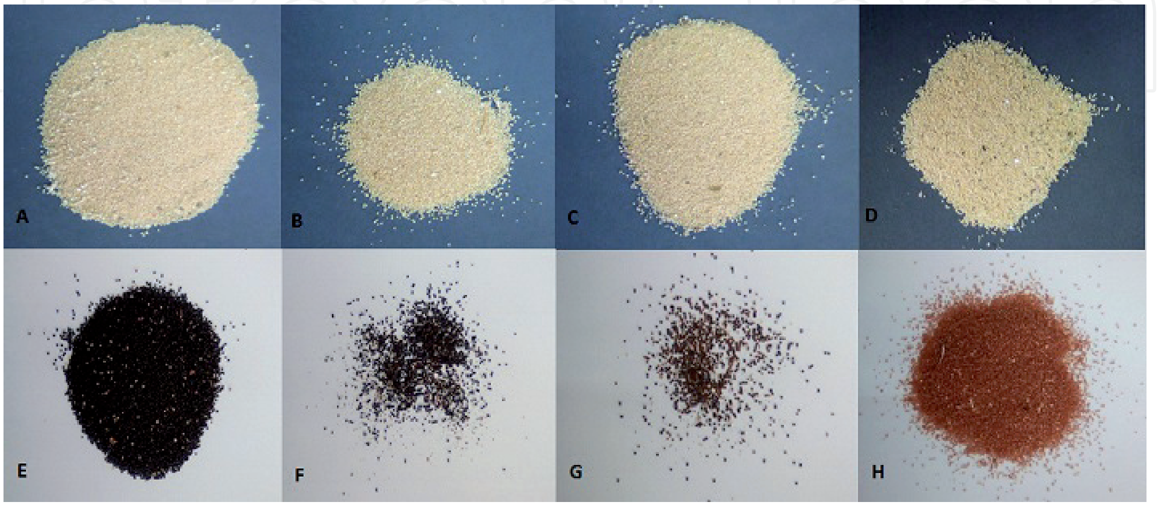

Figure 1.
Color of the amaranth seeds employed in the study. A, A. cruentus (France); B, A. hypochondriacus (Argentina); C, Amaranthus sp. (Mexico), D, A. hybridus (Mongolia); E, A. cruentus (Belgium); F, Amaranthus sp. (China); G, Amaranthus sp. (USA); H, A. caudatus (Belgium).

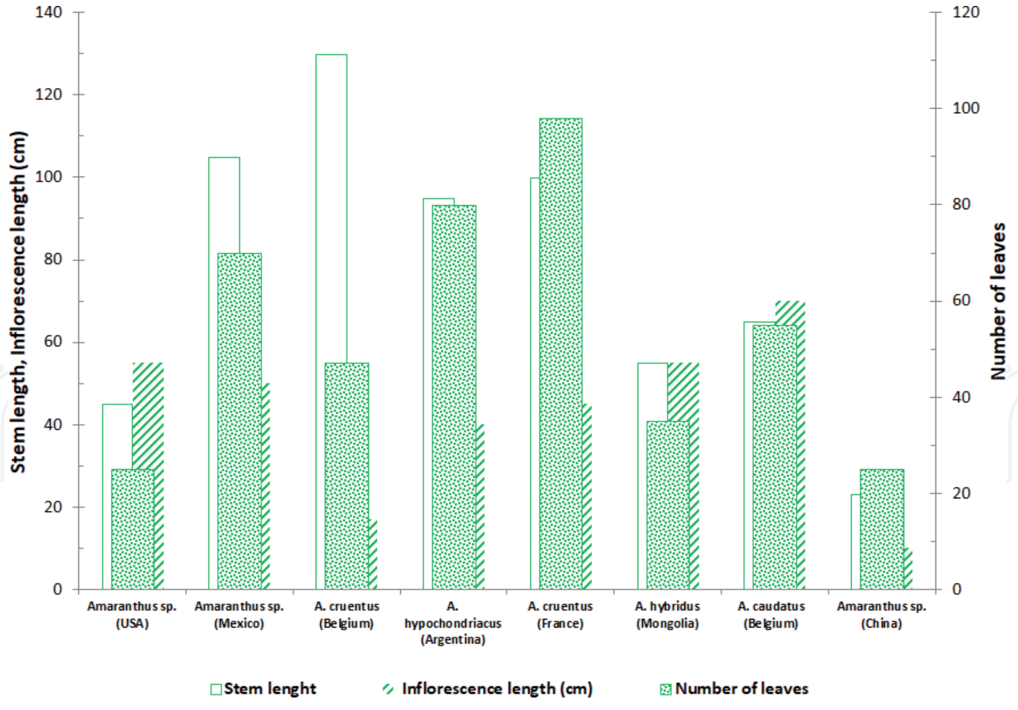

Figure 2.
Behavior of the biometric variables analyzed.

species *Amaranthus* sp. originating in China, and 70 cm on average for the species *Amaranthus caudatus*, from Belgium.

The Pearson correlation coefficient test applied to check the possible relationship between these two variables yielded a value of −0.74, which indicates that there is an inversely relationship between the size of the stem and the size of the panicle.

As regards the number of leaves at the time of amaranth harvest, as in the case of the previous indicators, interspecific differences are observed. The species that accumulated most leaves at the time of harvest were: *A. cruentus* (France), *A. hypochondriacus* (Argentina), and *Amaranthus sp.* (Mexico), with an average of between 70 and 98 leaves. The second range included *A. caudatus* (Belgium), *A. cruentus* (Belgium), and *A. hybridus* (Mongolia) with values between 35 and 55 on average. The last range included *Amaranthus* species from China and the USA, with an average of 25 leaves.

Analysis of the correlation between the stem size and number of leaves yielded a coefficient of 0.66, which indicates a moderate correlation between these two variables.

Finally, no significant differences were found between the weights of the seeds, with values ranging between 0.75 and 0.81 g. Only the amaranth species native of China showed a very low value (0.54 g) on average.

No correlation was observed between the weight of the seeds and the remaining variables.

The behavior of the different physiological variables analyzed is shown in **Figure 3**.

If we analyze the days for the seeds to emerge (**Figure 3**) in relation to **Table 2**, it can be observed that the only short-term germination species is *A. hybridus* (Mongolia). It took only 8 days to germinate. The long-term germination species were *A. caudatus* (Belgium) and *Amaranthus* sp. from China. The rest of the species belong to the medium-term range.

The species that attained physiological maturity first was the species *Amaranthus* sp. (USA) within 157 days on average, followed by the species *A. hypochondriacus* (Argentina) within 158 days on average. The species that took longest to reach physiological maturity was *A. cruentus* (France) within 193 days on average.

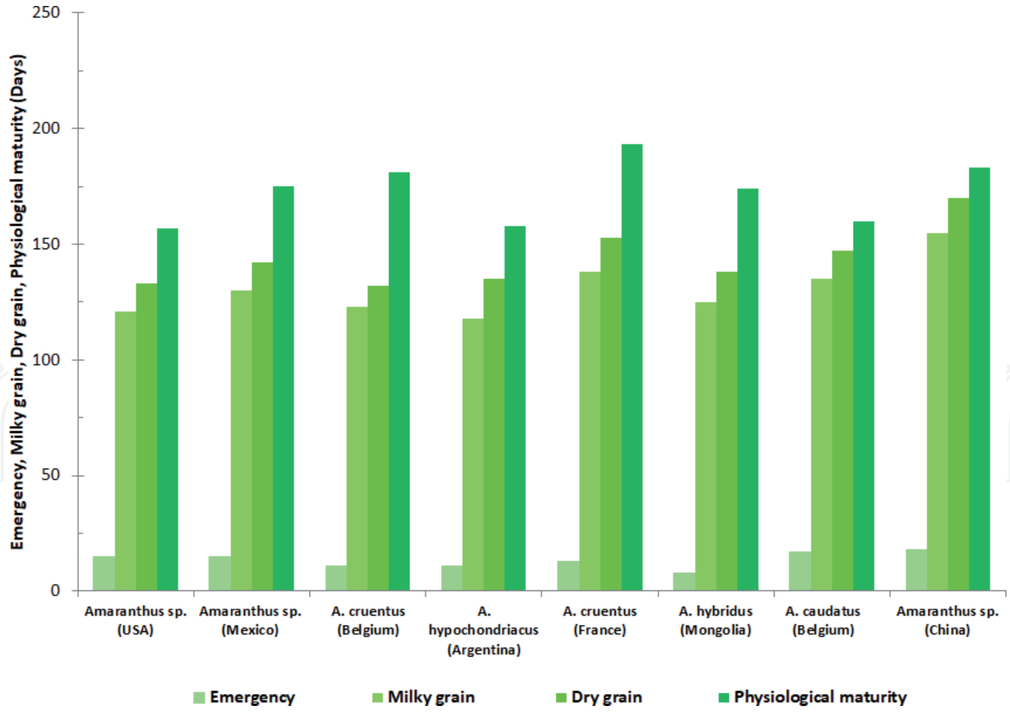

Figure 3.
Behavior of the physiological variables analyzed in the study.

As can be seen in **Figure 3**, there is a relationship between the days taken to acquire a milky grain appearance, a dry grain appearance, and physiological maturity, because these three variables refer to the same physiological process involved in the evolution of the seed in the plant.

However, analysis of the Pearson correlation coefficient test of the days required for seed emergence versus the days needed to reach physiological maturity yielded a coefficient of −0.062 which indicates that there is no correlation between the two variables. This indicates that the processes that regulate the emergence of the seed follow a different path to the processes that lead to reach the physiological maturity of the plant.

According to the physiological criteria, the species with a higher adaptive potential are the species from USA and *A. hypochondriacus*, due to its shorter time to reach the maturity.

Figure 4 shows a general analysis of all the variables considered to establish a cluster analysis.

In summary, if all the variables are considered together, it can be concluded that all the species presented an adequate ability response to the climatic conditions of the essay performed, because all of them reached the expected biometric and physiological values referred in the literature [8]. On the other hand, based on the time to reach the maturity, the promissory species are those from USA and Argentina (*Amaranthus* sp. and *A. hypochondriacus*, respectively).

The species that presented the lowest values for the different indicators analyzed was the species from China. As can be seen in **Figure 4**, it is also the most distant species in the cluster analysis. Unfortunately, the species has not been identified correctly, so it is difficult to establish whether this adaptability difficulty is due to genetic characteristics or climatic factors.

On the other hand, it is observed how the species *A. cruentus* presents phenotypic variability. **Figure 4** shows how the species from Belgium is grouped with *A. hypochondriacus*, while the species of *A. cruentus* from France is closer to *A. caudatus*.

This study is merely the starting point for adapting the amaranth species to the scenario of Cotopaxi. However, the results obtained are promising and will contribute to obtaining varieties that in the near future can be released to farmers.

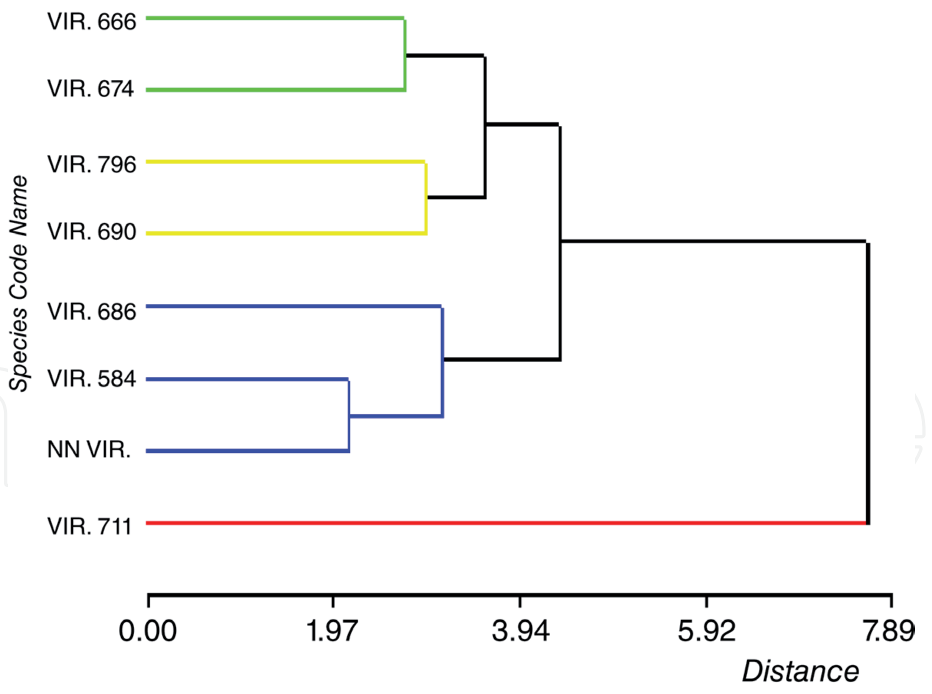

Figure 4.
Dendogram of the species under study. VIR 711 = Amaranthus sp. (China), VIR NN = A. caudatus (Belgium), VIR 690 = A. hybridus (Mongolia), VIR 686 = A. cruentus (France), VIR 674 = A. hypochondriacus (Argentina), VIR 666 = A. cruentus (Belgium), VIR 584 = Amaranthus sp. (Mexico), VIR 796 = Amaranthus sp. (USA). The values shown in the X-axis indicates distance among species based on the different variables analyzed.

4. Improvement of the drying process of amaranth seeds by using microwave energy

The second strategic line of investigation designed within the framework of the PROMAC was to improve the conservation of amaranth seed after it has been harvested.

Amaranth is usually harvested when its moisture content ranges from 22 to 30% [8, 21]. However, to ensure that this pseudocereal is well conserved for long periods of time, it is necessary to reduce these high moisture contents to levels ranging between 10 and 12% [8].

Amaranth seeds, like other seeds, can be dried naturally or artificially. In the Andean region of Ecuador, the drying of these seeds is carried out, fundamentally, in a traditional way, by exposing them to the air and taking advantage of solar energy. This method of drying has several disadvantages such as that there is little control over the process, as long periods of time (more than 15 days), and large open spaces are required for its completion and in many cases non-uniform drying occurs. Moreover, the seeds are exposed to climatic variations that reduce their viability and quality, making them susceptible to damage caused by environmental pollution, pests, and diseases [22–24].

To avoid the disadvantages of sun drying, several artificial drying methods have been developed [25–27]. However, none of these are suitable for satisfying all the needs and drying requirements of the different types of seed. The grain drying system may be classified into solar drying, batch drying, and continuous flow drying systems [26]. The dryers most commonly used to dry seeds are fixed bed dryers (batch) and sliding bed dryers, in their various configurations (concurrent, counter-current, and cross flows) [25, 26]. In relation with these systems, the drying process of several seeds, grains, and agricultural products, such as corn, wheat, rice, etc., has been widely investigated, and the results of the studies have been reviewed by several authors [25, 27–36]. However, in scientific literature, there are very few publications on the drying of amaranth seeds [21, 37, 38], reflecting the relatively scare attention paid to this particular seed. Moreover, in these studies, although the drying tests of amaranth seeds were carried out at different temperatures, the influence of this important operation parameter on the viability and quality of the seeds was not evaluated. Moreover, the small size of amaranth seeds (geometric mean diameter of ~1.15 mm) impedes their use in conventional systems and makes it difficult to achieve good results in the drying process [39].

Although such techniques have proved to be highly effective for drying, they are handicapped by the high energy consumption involved [40, 41]. This drawback has motivated the search for and development of other more efficient drying systems from the energy point of view which do not affect the viability and quality of the seeds. One such technique is microwave-assisted drying, that has been developed as an alternative technique to conventional methods of drying seeds and agricultural products, due to the numerous advantages it offers [22, 24, 42, 43]. Of these advantages, the following are noteworthy. High drying rates and, consequently, shorter drying times; a greater energy efficiency; the generation and more efficient use of heat, due to the deeper penetration of microwave energy in the products to be dried and to the reduction of heat loss since it is not necessary to heat the entire volume of the drying chamber to dry the product; precise and instantaneous electronic control that allows an adequate control of the drying temperature and a prompt commencement completion of the process; greater uniformity during the drying process; lower drying temperatures that will reduce the thermal gradients and drying imperfections of conventional methods and ensure the quality of the product to be dried, while preventing the migration of other materials to the surface, and offering a cleaner drying process, which does not generate secondary waste. For these reasons, it is not surprising that the number of studies aimed at evaluating the potential of the microwave oven for seed drying has increased enormously in recent years [22, 24, 42–47].

In this section, the main results obtained in the Research Project "Evaluation of the drying process in microwave oven of seeds of agricultural interest for the province of Cotopaxi", carried out in the Technical University of Cotopaxi, in Ecuador, are reported and analyzed with regard to the drying of amaranth seeds (*A. caudatus*).

The drying of the amaranth seeds, as part of this project, was carried out by means of two different experimental processes.

i. Microwave energy drying (a) in a microwave oven without any temperature control (at different power densities) and (b) in a microwave oven with temperature control (at different temperatures).

ii. Drying by the forced convection of hot air in electric ovens, at different temperatures (for comparative purposes).

4.1 Variables employed for the evaluation of the drying and germination of amaranth seeds

To evaluate the drying and germination of the amaranth seeds, three main variables were used: the drying time, energy consumption, and germination rate of the seeds.

Drying time is the time required to reduce the moisture content of the seed mass from its initial value to the desired final value under controlled drying conditions (temperature, pressure, seed mass, etc.). It is one of the main variables that characterize the drying process and is widely used for comparative purposes between one set of operating conditions and another as well as between different types of dryers. Moreover, this variable has a significant impact on others of vital importance, such as the energy consumption and the operating cost of the drying process.

Energy consumption is another very important variable in the drying process, as it is in other industrial processes. Drying is considered to be one of the unit operations with the highest energy consumption [48–50], because to eliminate water it is necessary to supply the latent heat of vaporization (~2400 kJ kg^{-1}). The minimum energy needed to perform this task is referred to as evaporation load [48]. However, commercially available conventional dryers, to compensate for the different heat losses that occur in them and/or in the heat supply system, consume an amount of energy that is significantly greater than the latent heat of vaporization [48]. In addition, energy consumption is directly related to the emission of greenhouse gases (GHGs) and other polluting gases and the operating cost of the process, so it is essential to reduce this consumption in order to reduce the carbon footprint and improve the economy of the drying process.

Finally, the rate or percentage of germination, according to the International Seed Testing Association [51] indicates the percentage of germinated seeds which have produced seedlings classified as normal in the conditions and the period specified. Germination is the emergence and development of the seed embryo of essential structures (shoots and roots) which, for a particular seed, are indicative of its ability to produce a normal plant under favorable conditions [52]. To determine the viability of a seed, tests are carried out on the basis of its germination capacity after the drying process or after any other type of treatment. The aim of the germination test is to determine the germination capacity of a seed lot, in order to be able to compare the quality of different batches of seeds that have been subjected to different treatments and also to be able to estimate their field planting value [51]. Moreover, the germination rate is useful for calculating the seed requirements for a given area or a desired number of plants, it follows, therefore, that the ability of seeds to germinate (viability) is one of the fundamental parameters to be evaluated in seed conservation.

4.2 The drying of amaranth seeds with microwave energy

4.2.1 In a microwave oven without any temperature control (at different power densities)

First, the amaranth seeds were dried in a rotating-turntable domestic microwave oven (General Electric Co., JES710WK), with a total output power of 700 W (**Figure 5**). In this oven, the drying of the seeds was evaluated at three microwave power densities: 0.875, 1.75, and 3.5 W/g.

The experimental procedure consisted in placing the mass of seeds required to obtain the desired power density in a paper box, which was in turn placed on the turntable of the microwave oven. The mass of seeds was weighed every 2 min, and the seeds were dried until a moisture content of 8% was obtained. Full details of the experimental set-up can be found elsewhere [53]. **Table 3** shows the results obtained in the drying process of the amaranth seeds in this oven at the power densities studied.

As can be seen in **Table 3** as the power density increased, from 0.875 to 3.5 W/g, the drying time required to reach a moisture content of 8%, their germination rate and energy consumption decreased simultaneously. The reduction in drying time (~72%) and energy consumption (~72%) are essential developments for reducing the operating costs of the drying process. However, the differences

Figure 5.
Microwave oven (General Electric Co., JES710WK).

Variables evaluated	Power densities (W/g)		
	0.875	**1.75**	**3.5**
Drying time (min)	31.3	15.3	8.7.
Estimated energy consumption (Wh)	364.8	178.5	101.5
Germination rate (%)	78	72	71

Table 3.
Results of the drying of amaranth seeds in a microwave oven (General Electric Co., JES710WK) at different power densities.

observed in the germination rate of the seeds are not statistically significant, and in all three cases, the germination rates are acceptable (>70%) [53]. This decrease in viability as a function of power density has also been observed in soybean [54], in corn seeds [55], and in wheat [56]. The decrease in the germination rate of the seeds with the increase in the power density may have been due to the fact that the drying temperature was also increased thereby affecting the ability of the seeds to germinate.

In summary, with the increase of power density in the microwave drying process, there is a simultaneous decrease in drying time, in energy consumption, and in the germination rate of the amaranth seeds. To avoid a decrease in the germination rate of the seeds, it is necessary to use low power densities.

4.2.2 In a microwave oven with temperature control (at different temperatures)

Subsequently, the amaranth seeds were dried, with microwave energy at a controlled temperature in a rotating turntable domestic multimode microwave oven (LACOR Model 69330) equipped with a 900 W magnetron, at a frequency of 2.45 GHz and a voltage of 220 V (see **Figure 6**). The microwave device is also equipped with a type K thermocouple connected to a PID Eurotherm 3216 L controller which controls the amount of power delivered and allows the temperature to be monitored and controlled continuously.

In this oven, 100 g of amaranth seeds, with an initial humidity of between 16 and 20% (wb), was placed in a microwave plastic container (105 mm long, 105 mm wide, and 45 mm high). The uncovered container was placed on the microwave

Figure 6.
Microwave oven (LACOR Model 69330).

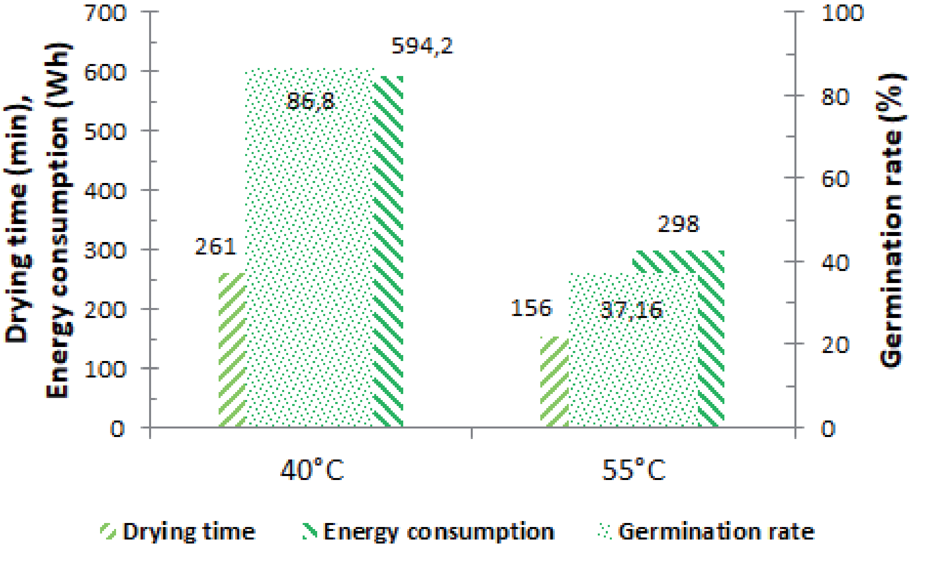

Figure 7.
Results of the microwave drying of amaranth seeds at the two temperatures studied and of their germination tests.

oven dish (315 mm in diameter), and the thermocouple was immersed in the bed of seeds. The amaranth seeds were heated up to the same drying temperatures used when drying by forced convection by hot air in the electric ovens analyzed in Section 4.3 (40 and 55°C, respectively). All the experiments were carried out with the turntable in stationary mode to avoid fluctuations in the measurements of seed temperature. The seeds were weighed every 30 min, and the drying process was considered to be completed when a humidity of 12% was obtained. For each drying temperature studied, the experiment was replicated five times. In each experiment, the electrical energy consumption was measured using a FLUKE 435 Series II energy analyzer. The effect of the drying temperature on the three variables evaluated is shown in **Figure 7**.

As can be seen in **Figure 7** at the lowest drying temperature (40°C), the highest values of the three variables studied were obtained: drying time (261 min), energy consumption (594 Wh), and germination rate of the seeds (86.7%). It can also be observed that at the highest drying temperature (55°C), there were significant decreases in the values of these variables: the drying time decreased by approximately 40%, energy consumption by 50%, and the rate of germination of the seeds by 57%. The decrease in these three variables with temperature was also observed in the microwave drying of corn seeds [57]. As we previously pointed out, the reduction in drying time (~40%) and energy consumption (~50%) are positive developments for reducing the operating costs of the drying process. However, the decrease in the germination rate of seeds to values as low as 37% is unacceptable. These results show that the drying temperature is a variable of vital importance in the drying process of amaranth seeds, due to the sensitivity of the germination capacity of these seeds to temperature.

In sum, with the increase in the microwave drying temperature, there is a simultaneous decrease in drying time, energy consumption, and germination rate of amaranth seeds. In order to obtain high germination rates in the drying process of amaranth seeds, it is necessary to dry the seeds at a temperature of 40°C.

4.3 Drying of amaranth seeds by forced convection of hot air in electric ovens

Finally, for comparative purposes, the amaranth seeds were dried by forced convection of hot air in two electric ovens, one conventional (**Figure 8a**, INCUCELL, LSIS-B2V/IC 55) and the other (**Figure 8b**, UTC-IEM-2017), designed and built in the Faculty of Engineering and Applied Sciences, of the Technical University of Cotopaxi, as part of the Research Project. These electric ovens have a total output power of 700 and 450 W respectively. The experimental procedure consisted in placing the mass of seeds in a container, which was in turn placed on the grill of the oven. The amaranth seeds were heat up to a drying temperature of 40°C (in the UTC-IEM-2017 oven) and 55°C (in the INCUCELL oven). The mass of seeds was weighed every 30 min, and the seeds were dried until a moisture content of 8% (in the INCUCELL oven) and of 12% (in the UTC-IEM-2017 oven) were obtained.

Table 4 shows the average values obtained for the three variables evaluated in the drying process performed in each electric oven.

In **Table 4**, it can be seen that the drying time and the germination rate of the seeds were lower (~36 and 23%, respectively) in the INCUCELL oven than in the UTC-IEM-2017 oven; while the consumption of electric power was 20% higher. This behavior is mainly due to the higher drying temperature and the lower final moisture of the seeds used in this oven, since the higher the drying temperature, the faster the rate of the process and, consequently, the lower the drying time. Moreover, the lower the final moisture content of the seeds, the greater the energy consumption required to evaporate the humidity. The lower germination rate of the seeds recorded at a drying temperature of 55°C in the INCUCELL oven agrees with the results obtained in the microwave drying process at this temperature. This result

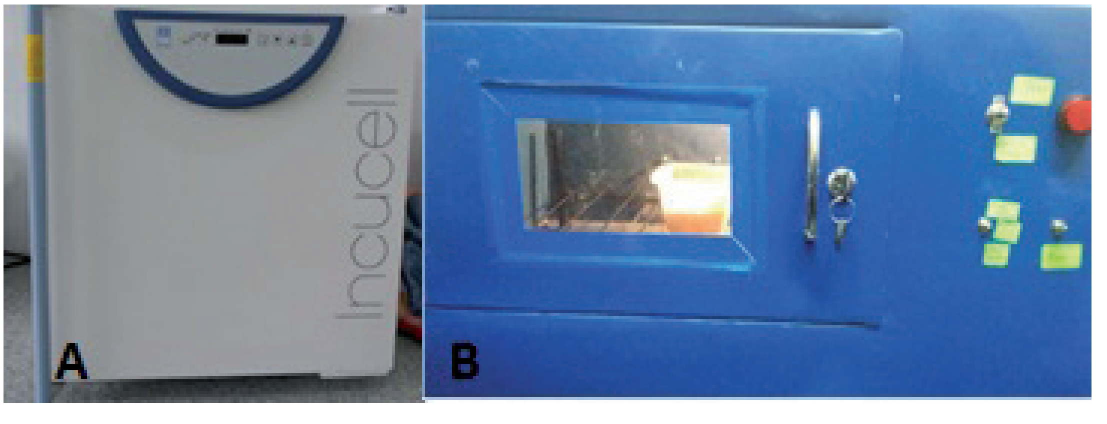

Figure 8.
(a) Electric oven (INCUCELL, LSIS-B2V/IC 55) and (b) electric oven (UTC-IEM-2017).

Variables evaluated	Electric ovens	
	INCUCELL, LSIS-B2V/IC 55	UTC-IEM-2017
	Drying temperature (°C)	
	55	**40**
Drying time (min)	248	336
Energy consumption (kWh)	2.89*	2.31**
Germination rate (%)	74	90.8

*Estimated.
**Measured.

Table 4.
Results of the drying of amaranth seeds by the forced convection of hot air.

confirms the decrease in the germination capacity of amaranth seeds at temperatures above 40°C.

In summary, the drying process of amaranth seeds by forced convection with hot air in the two ovens studied is characterized by high drying times and high energy consumption. In these ovens, the drying temperature should not exceed 40°C to avoid a decrease in the germination rate of the seeds to unacceptable values.

4.4 Comparative analysis between drying process of amaranth seeds by forced convection of hot air and microwave drying

In the previous sections, the results obtained in the drying process of amaranth seeds, using two different drying methods, were analyzed: drying with microwave energy at different power densities (Section 4.2.1) and at controlled temperatures (Section 4.2.2), and drying by hot air convection (Section 4.3.). In this section, a comparative analysis of the results obtained in the drying of this seed is carried out, using the same experimental parameters: drying temperature (40°C), initial seed mass (100 g), final moisture of the seeds (12%), but in two different drying installations: drying with microwave energy at controlled temperatures (Microwave oven LACOR Model 69330) and drying by hot air convection (electric oven UTC-IEM-2017).

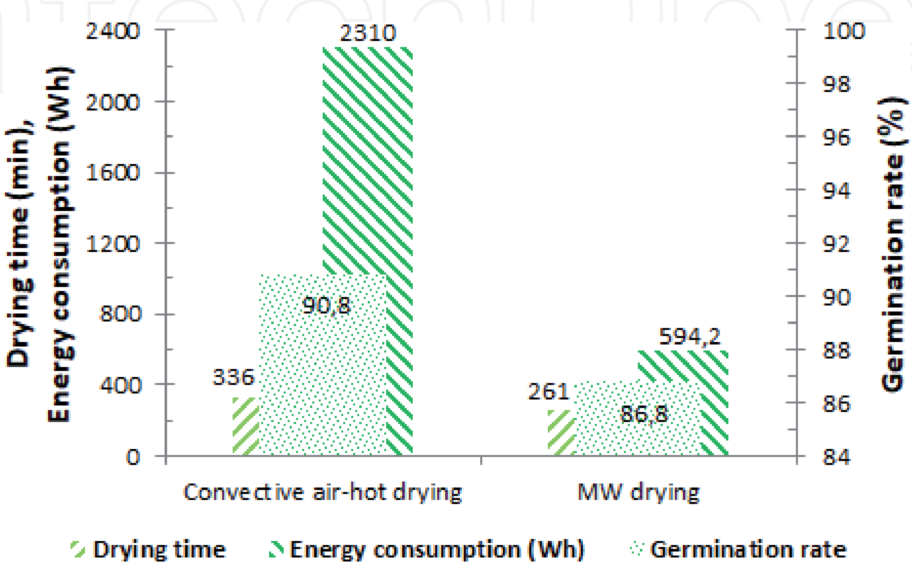

Figure 9.
Comparison of the microwave-assisted drying of amaranth seeds with hot air convection drying.

In **Figure 9**, it can be observed that when the amaranth seeds are dried with microwave energy, there is a simultaneous reduction in drying time, energy consumption, and germination rate of the seeds compared to drying by hot air convection. The decrease in energy consumption (~74%) and drying time (~22%) is considerable, making the microwave drying process much more competitive by reducing its operating costs. Moreover, the decrease in the germination rate of the seeds is small, <5%, so that the viability of the seeds is not significantly affected by microwave drying. These results show that microwave technology is a much faster and more efficient method than convection drying with hot air without affecting seed viability.

5. Future prospects

The results presented show the culmination of the phase I of the Program for Improvement and Selection of Amaranth in Cotopaxi (PROMAC). With the information obtained, it could, on the one hand, to determine which varieties, of the eight studied, have a greater adaptive potential, and, on the other hand, it was possible to verify that the drying strategy assisted by microwave energy can be a useful tool for the improvement of postharvest processes. However, there are still some issues to be resolved that will be addressed in phase II of the program. At this stage, the agronomic aspects (photoperiod, suitable soil type, and water requirements) to improve the crop will be addressed. In addition, biochemical (vitamin C content, among others) and nutritional studies will be carried out to know if these contents have been modified with adaptation strategies.

Regarding the improvement of the drying process of the amaranth seed, the established line of work aims to define more precisely what drying temperature range is ideal for optimizing seed conservation. Besides, the drying process for seeds from different varieties of amaranth will be evaluated to determinate the optimal drying conditions for conservation purpose. Physic-chemical and nutritional properties will also be evaluated after drying to figure out the effect of microwave energy on them. If the results performed at the laboratory scale were favorable, large-scale tests will be also carried out.

Finally, strategic alliances with other institutions in Ecuador and abroad will be developed, in order to carry out a characterization of the amaranth crops present in the country, so that the morphotypes can be determined and develop the different banks of germplasm for the conservation of the different varieties.

6. Conclusions

The preliminary results of the adaptation strategies for amaranth species confirm the capacity of the species to adapt, regardless of the origin of the material.

Based on the time to reach the maturity, the promissory species are those from USA and Argentina (*Amaranthus* sp. and *A. hypochondriacus*, respectively).

Although there are clear differences between the different collections of samples, the results of this study suggest that the species could be adapted to satisfy different requirements. For example, the species native to France (*A. cruentus*), Argentina (*A. hypochondriacus*), and Mexico (*Amaranthus* sp.) could be the most optimal for White-Grained Vegetable Improvement, taking into account that in Ecuador only one variety has been registered and released so far (INIAP-Alegría).

Likewise, the species from Belgium (*A. caudatus*) could serve as a decorative plant, due to its striking fuchsia-colored inflorescence.

Similarly, the leaves of the species native to Belgium (*A. cruentus*) could be used in the production of tea, since at a present in Ecuador sangorache (*A. quitensis*) is the only variety released for the consumption of leaf tea.

On the other hand, the results obtained related to the seed conservation strategies based on microwave technology indicate that:

Microwave power density exerts a significant influence on the drying process and the germination rate of the amaranth seeds. When the power density is increased, there is a simultaneous decrease in the drying time, energy consumption, and germination rate of the seeds. The highest germination rate (78%) was obtained at the lowest power density studied (0.875 W/g). For this reason, in order to obtain high germination rates, after the drying process, it is necessary to dry the seed at low power densities (i.e., 0.875 W/g or lower).

The drying temperature also has a significant effect on the microwave drying process and the germination rate of amaranth seeds. An increase in the drying temperature causes a simultaneous decrease in the drying time (~40%) and energy consumption (~50%) required to dry the seeds. However, there is also an unacceptable decrease (~57%) in the germination rate of the amaranth seeds with the increase in drying temperature. For this reason, it is necessary to dry amaranth seeds at a temperature of 40°C in order to obtain high germination rates.

The microwave drying of amaranth seeds, at a temperature of 40°C, could be a viable alternative to convective drying with hot air as this would lead to a reduction in the drying time of 22% and a saving of energy consumption of 78%. This saving of time and energy would make the microwave drying process of amaranth seeds much more competitive owing to the decrease in operating costs. The results obtained in this study show that microwave technology, at controlled temperature, would be a quick and efficient method of drying amaranth seeds without affecting their viability.

The work carried out to date within the framework of the program PROMAC in Cotopaxi has yielded promising results, which will serve as guidelines to develop the phase II of the PROMAC program.

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Conflict of Interest

The authors declare no conflict of interest.

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