TURMERIC

Post-harvest Operations

INPhO - Post-harvest Compendium

Food and Agriculture Organization
of the United Nations

TURMERIC: Post-Production Management

Organisation: Food and Agriculture Organization of the United Nations (FAO), AGST
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Last reviewed: 22/04/2004

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1. Introduction

As a dried rhizome of a herbaceous plant, turmeric is closely related to ginger. The spice is also sometimes called "Indian saffron" thanks to its yellow color.[1] The underground rhizome imparts a distinctive flavor to food but it is also used to provide food with a deep, indelible orange color. In the form of this fine, dried, yellow powder, turmeric is mostly sold to customers in developed countries. Turmeric is used in a wide variety of foods of the cuisines of Southern Asia but locally it also applies as an antiseptic for skin abrasions and cuts.[46]

1.1 Global production and trade

While there is speculation that turmeric may have originated from South or South-East Asia, its center of domestication is certainly the Indian subcontinent.[19,39] Currently, India is the major producer of turmeric, and it is also the major user of its own production (Table 1). Turmeric is part of Indian's culture: it is an important ingredient in curry dishes; it is also used in many religious observances, as a cosmetic, a dye, and it enters in the composition of many traditional remedies.[13,19,39]


Figure 1. **Figure 1a.**

Figures 1 - 1a. Turmeric (*Curcuma Longa L.*) [57]

Other producers in Asia include Bangladesh, Pakistan, Sri Lanka, Taiwan, China, Burma (Myanmar), and Indonesia. Turmeric is also produced in the Caribbean and Latin America: Jamaica, Haiti, Costa Rica, Peru, and Brazil.[19,56] Turmeric and curry powder exports from India are listed in Table 2.

Table 1: Turmeric production in India

	1995-96[a]	**1998-99**[a]	**2000**[b]
Area (hectares)	65,320	73,830	145,000
Production (metric tons)	252,437	329,436	600,000

[a]: Indian Spice Board Statistics: http://www.indianspices.com/html/s2200ssp.htm
[b]: Estimate, from Weiss, 2002

Table 2: Turmeric and curry powder exports from India[a]

		1998	**1999**	**2000**	**2001**	**2002**[b]	**2003**[b]
Turmeric	Quantity	28,875	37,298	37,776	44,627	35,000	32,000
	(metric tons)						
	Value (Rs. Lakhs)	8,306	12,914	12,352	11,558	8,463	9,938
	Value (US $1,000)c	19,776	30,830	28,553	25,246	17,786	20,547
Curry powder	Quantity	5,132	5,213	5,577	5,841	6,250	6,750
	(metric tons)						
	Value (Rs. Lakhs)	2,972	3,597	3,913	4,300	4,048	4,640
	Value (US $1,000) c	7,076	8,589	9,046	9,392	8,508	9,593

[a]: Indian Spice Board Statistics: http://www.indianspices.com/html/s0420sts.htm
[b]: estimate
[c]: 1 US$ ˜ 42 INR in 1998; 1US$ = 45.8 INR Aug. 2003

Ground turmeric powder exports from India were 12,000 t in 1999, and had doubled in 10 years from 1990 to 199956. During the same period, turmeric oil and oleoresin exports rose from 0.5 t to 4.0 t and from 150 to 250 t, respectively.[56]

Figure 2. Turmeric plantation [58]

1.2 Main consumption areas and trends

Asian countries consume much of their own turmeric production, except for Japan and Sri Lanka. Major importers are the Middle East and North African countries, Iran, Japan and Sri Lanka19,56. These importing countries represent 75% of the turmeric world trade, and are mostly supplied by the Asian producing countries.[56] Europe and North America represent the remaining 15%, and are supplied by India and Central and Latin American countries.[56] Taiwan exports mostly to Japan. [19] The United States imports of turmeric come from India at 97%, and the rest is supplied by the islands of the Pacific, and Thailand.[13]

Tables 3 and 4 show turmeric imports by the United States, United Kingdom and Japan. Quantities and prices for these countries were stable over the period 1997-2002. However, the increasing demand for natural products as food additives makes turmeric an ideal candidate as a food colorant, thus increasing demand for it. Additionally, recent medical research demonstrating the anti-cancer and anti-viral activities of turmeric may also increase its demand in Western countries.

As an indication of its value, the delivered price of turmeric on the New York market was 1,300 $/ton (Indian Madras fingers) and 1,455 $/ton (Indian Alleppey fingers) in mid-2001.[56]

Table 3: Turmeric imports in the US in the period 1998-2002 (metric tons; US $1,000)[a]

	1998	**1999**	**2000**	**2001**	**2002**
Turmeric (MT)	2,284	2,641	2,427	2,404	2,383
Value (US $1,000)	3,849	3,614	2,904	2,488	2,955

[a]*:Weiss, 2002*

1.3 Primary Products

There are two dominant types of turmeric found on the world market: 'Madras', and 'Alleppey', both named after the regions of production in India. The orange-yellow flesh Alleppey turmeric is predominantly imported by the United States, where users prefer it as a spice and a food colorant.[13] Alleppey turmeric contains about 3.5% to 5.5% volatile oils, and 4.0% to 7.0% curcumin.[13,15,56]

In contrast, the Madras type contains only 2% of volatile oils and 2% of curcumin.[13] The Madras turmeric is preferred by the British and Middle Eastern markets for its more intense, brighter and lighter yellow color, better suited for the mustard paste and curry powder or paste used in oriental dishes.[13,26] Turmeric produced in the Caribbean, Central and South America has low curcumin and volatile oil contents, and is darker26,53; it is not desired by the U.S. importers[13]. The Bengal type is preferred for use in dyes in India.[19]It is interesting to note that in the United States, turmeric is considered as a spice by the food industry, whereas it is classified as a food colorant by the FDA.[53]

Dried rhizome

Turmeric is mostly imported as a whole rhizome, which is then processed into powder or oleoresin by flavor houses and the industrial sector.[13,26] Rhizomes come as fingers, bulbs and splits. Fingers are the secondary branches from the mother rhizome, the bulb, and splits are the bulbs cut into halves or quarters before curing.[26,53] The fingers are 2 to 8 cm long and 1 to 2 cm wide, and are easier to grind than the more fibrous bulbs and splits, and therefore command a higher price.[13] Rhizome quality is judged by a clean and smooth skin, uniform skin and flesh colors, and a clean snap (or "metallic twang" as described by the Indian Ministry of Agriculture standards, Agmark) when broken.[56] Turmeric cleanliness specifications for import pertain to whole rhizomes.[12]

Turmeric powder

Ground turmeric is mostly used on the retail market, and by the food processors. Rhizomes are ground to approximately 60-80 mesh particle size.[15] Since curcuminoids, the color constituents of turmeric, deteriorate with light and to a lesser extent, under heat and oxidative conditions[15], it is important that ground turmeric be packed in a UV protective packaging and appropriately stored. Turmeric powder is a major ingredient in curry powders and pastes. In the food industry, it is mostly used to color and flavor mustard.[13] It is also used in chicken bouillon and soups, sauces, gravies, and dry seasonings.[53] Recently the powder has also been used as a colorant in cereals.[15]

Figure 3. Dried rhizomes[59]

1.4 Secondary and derived product

Curry powder

Turmeric is such an important ingredient in curry powder that it merits special mention. In its export statistics of spices, the Indian Spice Board specifically lists curry powder exports. (see table 2)

The turmeric content in curry powder blends ranges from 10-15% to 30%.[26] Typical Indian curry powder for meat and fish dishes contains 20-30% turmeric, 22-26% coriander, 12% and 10% cardamom and cumin, respectively, 4% or 10% fenugreek, ginger, cayenne, cloves and fennel in proportions from 1% to 7%.[26] Curry mixes for vegetarian dishes contain less turmeric, in the range of 5 to 10%, because of the bitter flavor it would impart to the dish.

Figure 4. Turmeric powder [60]

Oleoresins

Turmeric extractives, or oleoresins, are obtained by solvent extraction of the powdered or comminutated rhizome. This process yields about 12 % of an orange/red viscous liquid,

which, depending on the solvent used for extraction and on the turmeric type and cultivar, contains various proportions of the coloring matter, i.e. the curcuminoids, the volatile oils which impart the flavor to the product, and non-volatile fatty and resinous materials.[26]
The compounds of interest in turmeric oleoresin are the curcuminoids (40 to 55%), and the volatile oils (15 to 20%).15,26 The curcuminoids, which consist mostly of curcumin (1,7-bis(4-hydroxy-3-methoxyphenyl)-1,6-heptadiene-3,5-dione), and also demethoxycurcumin, and bisdemetoxycurcumin, can be further purified to a crystalline material, and will be used preferably in products where the turmeric flavor is undesirable, such as cheese, ice cream, beverages and baked products[13]. Curcumin has similar color characteristics than the synthetic food colorant tartrazine (FD&C yellow No. 5); however, unlike tartrazine, it is highly sensitive to light and alkaline pH, and is also degraded by heat and chemical oxidants. It is therefore not easy to use in food processes and products destined to long-term storage. It is nevertheless of commercial interest as a natural food colorant, and research is underway to improve its stability. [15]
Upon appropriate dilution with a vegetable oil, propylene glycol or polysorbates, the oleoresin gives a bright yellow liquid with the characteristic turmeric aroma, slightly bitter and pungent taste.[26, 56] The oleoresin may also be spray-dried on a sugar matrix such as maltodextrin to a powder, and can be used as a colorant in dry cereals or beverages.[15] The advantage of spray-dried turmeric oleoresin over ground turmeric powder is that it is devoid of starch, the predominant component in dried rhizome, and also proteins and other fibers.[15]
Turmeric oleoresin exported from India in 1998 was ranked third, after pepper and paprika oleoresins.[41]

Essential oil

Turmeric essential oil has little interest in the Western food industry, and it has no commercial value, as opposed to oleoresin.[26, 56] However, there is an increasing literature showing medicinal activities of turmeric, of which some are attributable to compounds present in the volatile fraction.27 Turmeric essential oil is obtained by distillation[56], or by supercritical fluid extraction of the powdered rhizome.[25] It is also the product of curcuminoids purification from oleoresins.[27, 55] The latter procedure, which consists in removing the oil with hexane or other lipophilic solvent, tends to alter the oil by loss of higher volatile molecules in the process of solvent evaporation; or, if alcohol is used as the solvent, artifacts are formed by esterification, etherification and acetal formation.[25]
The major compounds found in turmeric oil, up to 50-60%, are the sesquiterpene ketones, ß-, and ar-turmerone.[34] The sesquiterpenes zingeberene and ar-curcumene were either not reported, or found at as high as 25% and 35%, respectively[34, 56]. In general, there is a tremendous variation in published compositions of turmeric essential oils[34], and such variation was also observed in one study, within rhizomes collected from the sub-Himalayan region of the Tarai in India.[24]

Medicinal and biological properties of turmeric

Turmeric and isolated compounds from turmeric have demonstrated a remarkable variety of beneficial pharmacological activities. These include antioxidant[51,47], antiarthritic, antimutagenic[42], antitumor[44], anti-tumor promotion[52], antithrombotic[49], [50], antivenom by neutralizing the hemorrhagic effect of the venom in mice[21], antibacterial[40], antifungal[36], antiviral[38], nematocidal[29], choleretic and antihepatotoxic[31] activities. Low incidence of Alzheimers disease in regions where turmeric is extensively used in cuisine and as an herbal remedy suggests that it may protect against this disease since areas of high consumption such as those in India have very low Alzheimers incidence.[54] Further, a transgenic mouse model of Alzheimers has shown favorable response to curcumin therapy.[35]
Little or no toxicity is reported for humans receiving large (8 g/day18) therapeutic doses of curcumin, an important major component of turmeric. Rather than exhibiting dose dependent

toxicity, rodent experiments have shown that administration of the major metabolite of curcumin from early in life can extend median life span by 11%.30 The record of use of turmeric in Indian traditional ayurvedic medicine for hundreds of years supports its possible therapeutic efficacy and its likely low toxicity.[11,28]
All these findings about turmeric biological activities make it a good candidate for development of pharmaceuticals, nutraceuticals, or food ingredients with functional properties.

1.5 Requirements for export and quality assurance

1.5.1 Cleanliness specifications for spices

USA

When a food or cosmetic product is imported to the United States, the U.S. Customs notify the Food and Drug Administration (FDA), who initiates the inspection procedure. The FDA may sample a lot because of the nature of the product, or past history with similar products, but not all the lots are necessarily sampled by FDA. The FDA has determined Defect Action Levels (DALs) that define the level of foreign materials. Spices that are contaminated or adulterated need proper sanitation and reconditioning, or are destroyed or returned to the exporting country. When a lot needs sanitation or reconditioning, it is tested again after the procedure.
The American Spice Trade Association, Inc., has established cleanliness specifications that meet or exceed the FDA food defect action levels. ASTA has a voluntary commodity tracking program, which spice buyers may use as assurance that the spice purchased meet ASTA's cleanliness standards. This program requires that the lot is examined by an ASTA-approved independent laboratory, and passes all the requirements of the FDA, and the ASTA's cleanliness specifications. For more information on the ASTA's program, the reader should consult ASTA's web site, at http://www.astaspice.com. Tainter and Grenis[53] give a good overview of the FDA and ASTA's programs.
The ASTA Cleanliness Specification have become a standard for most exporting countries, who have built their facilities to meet those requirements. Importing countries that do not have specified standards may have used ASTA's specifications.[1]

Table 5: ASTA Cleanliness specifications for turmeric

Whole insects, dead	**Excreta, Mammalian**	**Excreta, Other**	**Mold**	**Insect Defiled/Infested**	**Extraneous Foreign Matter[1]**
by count	by mg/kg	by mg/kg	% by weight	% by weight	% by weight
3	11.1	11.1	3	2.5	0.5

[1] extraneous matter includes but is not restricted to: stones, dirt, wire, string, stems, sticks, non toxic foreign seeds, excreta, manure, and animal contamination.
ASTA sampling guidelines are as follows: precisely weighed samples are passed through a sieve (U.S. Standard No 8, or standard pepper sieve No 9) with a white paper underneath to observe foreign matter, insects and mammalian excreta. Rhizomes are examined for mold and defiling insects. Foreign matter is reported by count (insects) or by weight[1].

European Union

EU-member countries such as the U.K., Germany and the Netherlands have their own specifications. The European Spice Association (ESA) has a set of "quality minima for herbs and spices", but has yet to finalize the cleanliness specification standards for spices and spice products.

Table 6: ESA quality minima for turmeric

Turmeric product	**Total Ash(% w/w) max (ISO 928)**	**Acid Insoluble Ash (% w/w) max(ISO 930)**	**Moisture(% w/w) max (ISO 939)**	**Volatile oil(v/w) min (ISO 6571)**
Whole	8 [a]	2 [a]	12 [a]	2.5 [a]
Ground	9 [b]	10 [b]	10 [b]	1.5 [c]

[a]: British Standards Institute
[b]: Indian Standards Institute
[c]: European Spice Association

Extraneous matter and foreign matter should not exceed 1% and 2%, respectively. Should be free from live and/or dead insects, insect fragments and rodent contamination visible to the naked eye (corrected if necessary for abnormal vision).

Salmonella must be absent in (at least) 25 g of material. Yeast and mold: 10^5/g (target), absolute maximum: 10^6/g. E. coli: 10^2/g (target), absolute maximum: 10^3/g.

The European Union has fixed limits for aflatoxin, which should not exceed 10 ppb (total aflatoxins), and 5 ppb for aflatoxin B1. Individual European Union member countries have their own limits varying from 1 to 20 ppb. In the United States, aflatoxin B1 should not exceed 20 ppb.[2]

1.5.2 Turmeric oleoresin specifications

USA

The US Code of Federal Regulations 21 CFR 73.615 defines turmeric oleoresin as the "combination of flavor and color principles obtained from turmeric (Curcuma longa L.) by extraction using any one or the combination of the following solvents: acetone, ethyl alcohol, ethylene dichloride, hexane, isopropyl alcohol, methyl alcohol, methylene chloride, or trichloroethylene". The residue allowed in the product should not exceed that residue for that specific solvent: 30 ppm for acetone and chlorinated solvents, 50 ppm for methanol, ethanol, and isopropanol.[26]

Turmeric oleoresin is described as a "deep red or orange red, somewhat viscid liquid, with characteristic odor".[26] Turmeric oleoresin is valued for its curcumin content, but there is no standard specification for a minimum amount of curcumin.

1.5.3 Requirements for organic spices and products

To be sold as "organic", a product must be certified by an accredited certification body. There are slight differences in standards between countries. IFOAM, the International Federation of Organic Agriculture Movement, has established organic production, processing and trading standards, and tried to harmonize certification systems worldwide.[45] National and regional governments are also trying to work under a compatible minimum set of standards.

The European Union (EU) has established basic regulations for organic products in 1991 (Council regulation 2092/91), which apply to all products marketed as "organic", "biologic", "ecologic", "biodynamic", or similar terms. Imports may be accepted through procedures conforming to the exporting country's regulations, or by review of the certification documents, which accompany each shipment. The EU regulation sets a minimum standard,

and member states or private certification bodies may certify to standards that meet or exceed the EU regulation 2092/91.
In the United States, the Organic Food Production Act (OFPA) was passed into law in 1990, and since October 2002 has made organic production and processing uniformly regulated across all of the United States. The Agricultural Marketing Service (AMS) branch of the U.S. Department of Agriculture is administering the National Organic Program (NOP). [3]
In general, to be labeled "organic", a product must be grown following organic agricultural practices. Post harvest handling and processing must be done in certified facilities, whether on the farm or in food packing or processing facilities. Only mechanical, thermal or biological methods can be used in organic processing. The use of genetically modified organisms (GMO) (plants, animals or bacteria) and products of GMO are prohibited in organic production. Likewise, ionizing radiation and sewage sludge are prohibited from organic agricultural practices. Labels of organic products must identify the certification body.
Japanese organic standards (Japan Agricultural Standards, JAS) generally follow the U.S. NOP standards. However, JAS does not allow organic labeling on products that contain less than 95% organic ingredients (the EU and NOP allow labeling "made with organic ingredients" for products that contain between 70% and 95% organic ingredients).
In addition to standards pertaining to the production of organic products, IFOAM basic standards include environmental and social justice requirements. For example, IFOAM basic standards [6] include "2.1.1: operators shall take measures to maintain and improve landscape and enhance biodiversity quality"; or "8.1: operators shall have a policy on social justice"; or "8.5: operators shall provide their employees and contractors equal opportunity and treatment, and shall not act in a discriminatory way"; or "8.6: children employed by organic operators shall be provided with educational opportunities".
IFOAM, EU and U.S. organic standards include lists that allow the use of specific synthetic, non-agricultural or non-organic agricultural substances. If a substance does not appear on those lists, it must not be used on an organic product, in the process or as an ingredient. Those lists differ slightly, and operators producing for export markets to Europe, United States and Japan should consult and compare those lists carefully to assure compliance in each country. [4]
To comply with organic standards and practices, the operator must document all farming and post harvest activities. The following records must be maintained: farm field map, field history, activity register, input records including purchases, output records including sales, harvest records, storage records, pest control records, movement records, equipment cleaning and labeling. All such documentation must meet specific standards that are enumerated in directives issued by the certification agencies.
In the processing plant, the operator must present an "organic handling plan" that will show how contamination from prohibited materials and commingling with non-organic products will be prevented. This includes a detailed description of the process, receiving and storage of ingredients and finished products, cleaning and sanitation of the processing equipment, facilities pest management, and a documentary "paper trail" that must permanently record all of the above.
For the spice and oleoresins production, ionizing radiation and the use of volatile synthetic solvents are prohibited for use in the processing of organic products.

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[1]Percent calculation formula are given in the ASTA Cleanliness Specifications manual, method 14.1, page13-1713.

[2] Detailed specifications for quality standards, pesticide residues and aflatoxin levels for some individual European countries may be found at:
http://www.indianspices.com/html/s1490qua.htm
[3] The final rules to implement the OFPA were published in the Federal Register in 2000 (7 CFR Part 205).
[4] For reference, the IFOAM lists are contained in Appendices 1, 2, 3, and 4 of the IFOAM basic standards (http://www.ifoam.org). The USDA National List for allowed non organic (non agricultural and agricultural) ingredients is under § 205.605 and § 205.606 of the Federal Register, Vol. 65, No 246, and can be found at:
http://www.ams.usda.gov/nop/NationalList/FinalRule.html
EU lists for processing are under Annex VI-A, VI-B, and VI-C. EC 2092/91 regulation and amendments may be found by searching Euro-lex, at:
http://europa.eu.int/eur-lex/en/search/search_lif.html, using the year descriptor "1991", and document number "2092".

2. Post-Harvest Management Aspects

2.1 Harvest

Turmeric readiness for harvest is indicated by the drying of the plant and stem, approximately 7 to 10 months after planting, depending on cultivar, soil and growing conditions. The rhizome bunches are carefully dug out manually with a spade, or the soil is first loosen with a small digger, and clumps manually lifted. It is better to cut the leaves before lifting the rhizomes. Rhizomes are cleaned from adhering soil by soaking in water, and long roots are removed as well as leaf scales. Rhizomes are then further cured and processed, or stored for the next year's planting. [10, 26, 19, 56]

Rhizomes for seed purposes must be stored in well-ventilated rooms to minimize rot, but covered with the plant dry leaves to prevent dehydration.[26] They can also be stored in pits covered with sawdust, sand, or panal (Glycosmis pentaphylla) leaves that may act as insect repellent.[10] The Indian Institute of Spice Research recommends the following fungicides as a pre-storage dip treatment for rhizome seeds: quinalphos at 0.075%, and mancozeb at 0.3%.[10] Studies indicate that bulbs (mother rhizomes) are preferred to fingers as a seed stock.[26]

2.2 Post-harvest handling: curing, drying and polishing

Turmeric rhizomes are cured before drying. Curing involves boiling the rhizomes until soft. It is performed to gelatinize the starch for a more uniform drying, and to remove the fresh earthy odor.[26,56] During this process, the coloring material is diffused uniformly through the rhizome. Recommendations as to the acidity or alkalinity of the boiling water vary by author. The Indian Institute of Spice Research, Calicut, Kerala, and the Agricultural Technology Information Center simply recommend boiling in water for 45 min to one hour, until froth appears at the surface and the typical turmeric aroma is released.[10] They report the color deteriorates as a results of over-cooking, but that the rhizome becomes brittle when under-cooked. Optimum cooking is attained when the rhizome yields to finger pressure and can be perforated by a blunt piece of wood.[26, 56]

Boiling in alkaline water by adding 0.05% to 1% sodium carbonate, or lime, may improve the color.[26, 56] For the curing process, it is important to boil batches of equal size rhizomes since different size material would require different cooking times. Practically, fingers and bulbs are cured in separate batches, and bulbs are cut in halves. Cooking may vary from one to four

or six hours, depending on the batch size [26]. Curing is more uniform when done with small batches at a time. It is recommended to use perforated containers that allow smaller batches of 50 to 75 kg, which are immersed in the boiling water; by using this method, the same water may be used for cooking several batches.[10, 56] Curing should be done two or three days after harvest, and should not be delayed to avoid rhizome spoilage.[10] The quality of cured rhizomes is negatively affected for material with higher initial moisture content.[43]
Benefits of curing turmeric include reduction of the drying time, and a more attractive product (not wrinkled) that lends itself to easier polishing.[26] However, it was reported that while the total volatile oil and color remained unchanged, curcuminoid extractability might be reduced.[15] The curing by boiling process has the advantage of sterilizing the rhizomes before drying.
Slicing the rhizomes reduces drying time and yield turmeric with lower moisture content as well as better curcuminoid extractability.[15,26] In rural Bolivia, slicing the boiled rhizomes is done by women. The "Fundación Poscosecha", with the support of FAO has developed a slicing machine in order to ease the women's work. The slicing machine has a simple design, is easy to use, and can be made at a low cost. It consists of a metallic structure (rack), a transmission system, and a metallic box containing a disc and two stainless steel circular blades. The transmission system is made of a pinion, an escape wheel, and a chain, and has a transmission report of 3:1. The slicing machine is all metallic, and when well maintained (lubrication of axles and bearings), it can be used up to eight years. The advantages of this machine are ease of use and installation, and ease of transport (it weights about 40 kg). It has a high capacity (up to 120 kg/hr), and considerable reduces the traditional cutting by hand.

Figure 5: Turmeric Slicing Machine

(Rodajadora de Curcuma)[61]

Cooked fingers or bulbs are dried to a moisture level of 5% to 10%. Sun drying may take 10 to 15 days, and the rhizomes should be spread in 5-7 cm thick layers to minimize direct sunlight that results in surface discoloration.[10] Turmeric is one of the spices for which it is more advantageous to use mechanical driers because of the sensitivity to light. Those can be drums, trays, or continuous parallel or cross-flow hot air tunnels.[56] Like with ginger rhizomes, the optimum drying temperature is 60 ºC.
An example of solar drier was developed in Bolivia, the "Secadora Solar". It was designed to dry turmeric and ginger under the hot and humid conditions of tropical Bolivia, but it can also be used to dry other foods.

The maximum temperature achieved by the drier depends on the outside climatic conditions. The body of the machine is quite simple, it consists of a metallic rack supporting the rest of the components, two parallel inserted plastic trays where the products are put on to dry, and a plastic cover that should be designed to assure major protection from ultraviolet radiation. Ideally, the plastic should be black, or contain a UV protector. Because the sun is serving as energy source, satisfying outputs cannot be achieved in regions where cloudiness and humidity is high. Approximately 4 KWH/m^2 of solar energy is needed to use these techniques successfully. The best outputs are obtained in regions with a humidity of 40% to 60% and average temperatures of 14º to 18ºC.

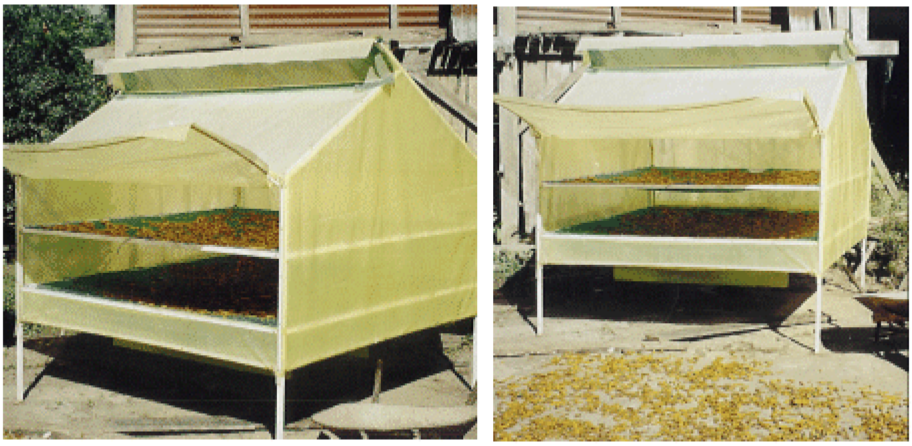

Figure 6: Description of Drying Machine

(Secadora Solar de Curcuma)[62]

The advantages of this type of drier are simple construction with appropriate technology, ease of dismantling and transport, and versatility of use.[25] [5]

Many types of solar driers or solar equipments can be found on Internet. For example:

http://www.itdg.org/html/technical_enquiries/docs/solar_drying.pdf

http://www.fao.org/inpho/isma?m=library&txt=expert&i=INPhO&p=SimpleSearchFrame&lang=en&n=1&op=or

http://solarcooking.org/

http://www.areed.org/training/technology/solar_dryer/

Dried fingers are polished to remove scales and rootlets from the rhizomes by using rotating drums lined with a metallic mesh that abrades the rhizome's surface.[10, 43] Turmeric powder suspended in water is sprinkled over the rhizomes at the final stage of polishing to give an attractive color [10, 26].

2.3 Grading, packing and storage

Quality specifications are imposed by the importing country, and pertain to cleanliness specifications rather than quality of the spice (see cleanliness specifications in 1.5.1). Proper care must be taken to meet minimum requirements, otherwise a lot may be rejected and need further cleaning and/or disinfection with ethylene oxide or irradiation.

Bulk rhizomes are graded into fingers, bulbs and splits.[13] The Indian Standards for turmeric follow the Agmark specifications (Agricultural Directorate of Marketing), to insure quality and purity. [6]

Table 8: Agmark standards for turmeric rhizomes [a]

Grade	Flexibility	Broken pieces, fingers<15 mm	Foreign matter	Defectives	Percentage of bulbs by weight, max.
		No more than (% by weight)	No more than (% by weight)	No more than (% by weight)	
Alleppey fingers [b]					
Good	Hard to touch	5	1	3	4
Fair	Hard	7	1.5	5	5
Fingers, other than Alleppey [b]					
Special	Hard to touch, metallic twang on break	2	1	0.5	2
Good	Same	3	1.5	1	3
Fair	Hard	5	2	1.5	5
"Rajapore" fingers [c]					
Special	Hard to touch, metallic twang on break	3	1	3	2
Good	Same	5	1.5	5	3
Fair	Hard	7	2	7	5
Non specified	-	-	4	-	-
Bulbs [d]					
Special	-	-	1	1	-
Good	-	-	1.5	3	-
Fair	-	-	2	5	-

[a]: *http://www.turmeric.8m.com/standards.html*
[b]: *Fingers shall be of secondary rhizomes of Curcuma longa L.; shall be well set and close grained; free from bulbs; be perfectly dry and free from weevil damage and fungus attack; not be artificially coloured with chemicals.*
[c]: *same as (b); have the characteristics of the variety; admixture of varieties of turmeric allowed at a maximum of 2%, 5%, 10% and 10% in the four grades, respectively.*
[d]: *Bulbs shall be primary rhizomes of Curcuma longa L.; shall be well developed, smooth and free from rootlets; have the characteristics of variety; be perfectly dry and free from weevil damage and fungus attack; not be artificially coloured with chemicals.*

Rhizomes may be packed in jute sacks, wooden boxes or lined corrugated cardboard boxes for shipping.[56] Storage of bulk rhizomes should always be in a cool and dry environment, to prevent moisture absorption and chemical degradation. Turmeric has traditionally been adulterated with related *Curcuma* species, specifically *C. xanthorrhiza Roxburg*, *C.*

aromatica, and *C. zedoaria*.[19, 26, 56] However, due to strong competition between spice processors, the quality of turmeric destined to the Western markets is usually guaranteed by the exporter in contracts negotiated between the buyer and the seller.

2.4 Grinding and milling

Grinding is a simple process involving cutting and crushing the rhizomes into small particles, then sifting through a series of several screens[53]. Depending on the type of mill, and the speed of crushing, the spice may heat up and volatiles be lost. In the case of turmeric, heat and oxygen during the process may contribute to curcumin degradation. Cryogenic milling under liquid nitrogen prevents oxidation and volatile loss, but it is expensive and not widespread in the industry.[53] Ground spices are size sorted through screens, and the larger particles can be further ground. Most quality control laboratories use the U.S. Standards (U.S.S.) screen size system. However, there are other systems that use a different numbering, and comparisons between specifications may be difficult.[53] For instance, the U.S.S. screen numbering goes from 4 to 80 mesh screens (i.e. 4 to 80 openings per inch), while the Mill screen system goes from 4 to 55 mesh with different increments than the U.S.S. system. [7]

Table 9: Agmark standards for turmeric powder [a]

Grade	**Moisture (% w/w) max**	**Total ash (% w/w) max**	**Acid insoluble ash max (% w/w)**	**Lead max (ppm)**	**Starch max (% w/w)**	**Chromate test**
Turmeric powder [b]						
Standard	10	7	1.5	2.5	60	Negative
Coarse ground powder [c]						
Standard	10	9	1.5	2.5	60	Negative

[a]: *http://www.turmeric.8m.com/standards.html*
[b]: *Ground to such a fineness that all of it passes through a 300 micron sieve*
[c]: *Ground to such a fineness that all of it passes through a 500 micron sieve*

2.5 Extraction: oleoresin production

Since curcumin is the compound of interest in turmeric rhizome, it is important to know the solubility of curcumin in different solvents in order to choose the appropriate solvent. Curcumin is soluble in polar solvents (acetone, ethyl acetate, methanol, ethanol), and quite insoluble in non-polar solvents such as hexane, and insoluble in water.[55] Dried powdered rhizomes are extracted by percolation with the polar solvent. The particle size, uniform packing in the extractor, temperature and percolation rate of the solvent are all important parameters for optimum extraction.[26] If the oleoresin is the desired product, the solvent is completely evaporated by distillation at 45-55 °C.[56]

If curcumin is the final product, the solvent is only partially removed, and the color material is separated from the solvent by freezing, then centrifugation or vacuum-filtration.[55] At this step, curcumin is further purified with a wash with hexane. Hexane will extract all the gummy matter, oils, fats, and volatile essential oils that would otherwise impart a turmeric flavor. The yield of curcumin from dried turmeric root is about 5%.[13] Oleoresin composition

will vary greatly with the type of solvent, temperature and extraction methods, in addition to the effect due to quality of the raw material.[15] The commercial methods of extraction will vary by manufacturer and are proprietary information.[26] The yield of oleoresin from dried root is typically 10-12%.[13, 15, 26]
For organic production, synthetic solvents are not allowed [8]. Solvents derived from petrochemicals such as hexane, pentane, di- and tri-chloroethanes, acetone, cannot be used in organic production. The International Federation of Organic Movement (IFOAM) specifies that only ethanol, water, edible oils or carbon dioxide are allowed[9]. Therefore, possible solvents for curcumin extraction would be ethanol in the first step, and wash with vegetable oils and water for purification. There is no published study by using these restricted solvents, and it would be worth pursuing experimentally.

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[5](For further information see Fundación Poscosecha, "Manual de Fabricación de Secadora Solar de Curcuma")
[6] Marketing of Turmeric in India, Agricultural Market, Series No. 148, Directorate of Marketing and Inspection, Government of India, Nagpur, 1965.
[7] For a detailed discussion on particle size specifications, please refer to Tainter and Grenis (2001). The Indian Agmark standards for turmeric powder refer to a grain size that would pass through a 300 micron sieve (turmeric powder), and 500 micron sieve for coarse powder (http://www.turmeric.8m.com/standards.html).
[8] Federal Register, 7 CFR Part 205
[9] (IFOAM standards, Appendix 4)

3. Proposed improvements

3.1 Cultivar

In India, the region of production determines the name of the type of turmeric. Although the average productivity of cultivated turmeric remains at an average low, breeding for crop improvement is difficult due to plant sterility.[19] The Indian Institute of Spice Research in Calicut, Kerala, has however proceeded to crop improvement by clonal selection. This Institute currently maintains a collection of 500-600 accessions of turmeric, all named for the distinct locations from which each was collected.[19] Other institutions are also proceeding towards a similar effort, observing production yields and qualities of turmeric collected from the Tarai area of Northern India transplanted under plain conditions.[24] The following Indian cultivars were released by the Indian Institute of Spice Research.

Table 10: Indian cultivars released by the Indian Institute of Spice Research [3, 10, 41]

Turmeric cultivar	Fresh yield (T/ha) [a]	Maturity (days)	Curcumin %	Oleo-resin %	Essential oil %	Dry recovery %	Rhizome color
Suvarna	17.4 – 43.5	200	4	13.5	7	26	Deep orange
Suguna	29.3 – 60.3	190	4.9	13.5	6	20.4	Orange
Sudarshana	28.8 – 54.9	190	7.9	15	7	20.6	Orange
Prabha	37	205	6.5	15	6.5	19.5	Reddish yellow
Prathibha	39.1	225	6.5	16.2	6.2	18.5	Reddish yellow

[a]: First value is observed yield, second value is potential yield
Source: http://www.iisr.org/varieties/

3.2 Post harvest handling

It is recommended that washed rhizomes be dried as soon as possible to minimize contamination, mold growth and fermentation. Boiling the turmeric rhizome in the curing process significantly reduces the microbial load on the rhizomes[26]. If the rhizome is additionally dried in a mechanical drier, the potential for dust contamination is lessened. After drying, specific equipment is suggested for optimum cleaning of the dried rhizomes[43]: a plain sifter and an air screen separator will help remove small materials such as dead insects, excreta and extraneous matter, while a rotary knife cutter, a screen separator and a de-stoner will help remove residual insects and other extraneous matter.

In spite of the curing and drying process, turmeric still carries a heavy bacterial load[33]. Specifically, toxigenic molds are reported on turmeric and other spices. Among the post-processing disinfection treatments available for spices, ethylene oxide is currently approved for use on spices in the United States with a maximum residue of 50 ppm after treatment.[53] However, ethylene oxide is dangerous to apply, and highly carcinogenic by inhalation. It has to be applied in specially-built facilities. The use of ethylene oxide is banned in the European Union and in Japan.[17] The U.S. Environmental Protection Agency (EPA) has a maximum tolerance residue for ethylene oxide of 50 ppm on spices (40 CFR, 180.151). Propylene oxide is an alternative to ethylene oxide, but is not as efficient.[53] If ethylene oxide is withdrawn form the market, it is likely that propylene oxide will follow the same route.

Irradiation is becoming an increasingly accepted technique to sterilize spices and other food products, mostly meat products and fruits.[33] It too requires specially built and secure facilities. The common dose applied to spices is 3 to 10 kGy. By law, a spice irradiated once cannot be irradiated a second time; therefore, bulk irradiated spices must be well labelled to avoid a second irradiation if it enters as an ingredient in a meat or other product that will be irradiated.[53] Irradiation of turmeric rhizomes with 10 kGy at a dose rate of 19 Gy·min-1 was reported not to modify the composition of volatile oils extracted after one week of storage at 5 °C.17 The antioxidant activity as measured by the protective ability of linoleic acid oxidation (thiobarbituric acid value and peroxide value) was also reported to be unaffected by irradiation.[17] Laws allowing irradiation on foods vary greatly by country within the European

Union. Several test methods are available to detect whether a spice has been irradiated. One method is based on the observation that irradiated spices exhibit thermoluminescence. However, it appears that inorganic dust present in spice powders have the highest thermoluminescence capacity from irradiation. Therefore, one study suggested that salt (NaCl) could be added before irradiation and serve as an indicator for irradiation.[14] This may not be very practical for all spices. Other reported methods include electron spin resonance spectroscopy.[33,53]

3.3 Storage

Turmeric pigment is highly unstable as compared to the yellow synthetic colorant, tartrazine.[15] However, if protected from light and humidity, the curcuminoid pigments in turmeric powder and oleoresin are stable. Therefore, turmeric rhizomes and powder should be stored away from light and in a very dry environment.[43] Additionally, all water or ethanol solvent should be removed from the oleoresin to assure pigment stability.[15]

Annex 1: Useful Sites

Indian Spice Board:
http://www.indianspices.com
2. Indian Institute of Spice Research:
http://www.iisr.org
3. Indian Institute of Spice Research, Agricultural Technology Information Center:
http://www.iisr.org/atic/
4. Indian Ministry of Food Processing Industry:
http://mofpi.nic.in/technologies/rural/spices&plantation/spi_dehydraginger.htm
5. Organic Trade Association
http://www.ota.com
6. International Federation of Organic Movements
http://www.ifoam.org
7. American Spice Trade Association
http://www.astaspice.org
8. U.S. Food and Drug Administration Office of Regulatory Affairs Import program
http://www.fda.gov/ora/import/default.htm

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Annex 3: List of Figures and Tables