STUDY ON DIFFERENT DRYING METHODS OF RED CHILLI (*Capsicum annuum* L.)

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A Thesis Submitted to the Post-Graduate Committee of the Yezin Agricultural University in Partial Fulfillment of the Requirements for the Degree of Master of Agricultural Science in Food Engineering and Technology

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DECLARATION OF ORIGINALITY

This thesis represents the original works of the author, except where otherwise stated. It has not been submitted previously for a degree or to any other University.

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ABSTRACT

The experiments were carried out at Postharvest Research Institute (PHRI), Department of Agriculture and the Division of Postharvest Technology, Advanced Centre for Agricultural Research and Education (ACARE), Yezin Agricultural University (YAU) during April to August in 2019. The first experiment was conducted to investigate the optimum temperature of hot air oven drying at 50ºC, 60ºC and 70ºC on drying of chilli. In the second one, different drying methods of open sun and solar tunnel drying were used as treatments. Before drying the chilli, the second factor, blanching and non-blanching were performed in both experiments. The hybrid cultivar of red chilli (Champion 777) was used as experimental material. The data on moisture content (% wb), drying hour, drying rate (%/h), water activity (aw), color difference (ΔE), browning index (BI), ascorbic acid content (mg/100g) and aflatoxin content (ppb) were recorded. The final moisture content ranged from 5.8 to 7.3% (w.b) depending on drying method. In oven drying method of red chilli, 50ºC showed the longest drying time followed by the drying temperature of 60ºC and 70ºC. Moreover, that treatment not only could minimize browning index and color difference but also could retain the ascorbic acid content compared to drying at 60ºC and 70ºC. In open sun drying method, the longest drying time was 25 hours for non-blanched and 23 hours for blanched chilli. Most of the treatments showed no aflatoxin content and it was much below the permissible level in blanched chilli of solar tunnel drying method. From these findings, the red chilli dried using solar tunnel had considerably lower moisture content, water activity with less in browning index and color difference than open sun drying. Moreover, solar tunnel drying method retained more ascorbic acid content than open sun dried samples. Therefore, solar tunnel drying method was much better than open sun drying method with respect to less time for drying, low moisture content, brighter red color with high ascorbic content. As a pretreatment, blanching should be done before drying red chilli due to lower browning index, less moisture content and higher ascorbic acid content than non-blanched chilli.

Keywords: ascorbic acid, aflatoxin, color difference, drying methods and moisture content

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CHAPTER I
INTRODUCTION

Chilli is a vegetable plant belonging to the family of Solanaceae (Ajaykumar, Sandeep & Madhukar, 2012). Major chilli growing countries are India, China, Indonesia, Korea, Pakistan, Egypt, Mexico, USA, Italy and Hungary (Kumar, et al., 2017). Chilli is an important culinary crop in Myanmar and it is a quintessential spice in every Myanmar cuisine. Chilli is grown throughout the country and it is a seasonal and annually grown cash crop. There are many varieties of chilli in Myanmar and total cultivated area of chilli was 109,510 hectares in 2017-2018 (DOA, 2018). Green chilli is used for hot flavor and spices in salads and dried chilli powder is used in dishes as condiments for flavouring and colouring in Myanmar cuisines. Chilli is rich in vitamin A, B, C and E with minerals like folate, molybdenum, potassium, manganese, copper and thiamin. Chili has seven times vitamin C more than orange. It protects from heart disease by dilating blood vessels (Ajaykumar, Sandeep & Madhukar, 2012). Chilli is widely used all over the world and named as “Wonder Spice”. It is mostly consumed in the form of dried powder or fine flake as a condiment (Turhan, Turhan & Sahbaz, 1997).

Fresh red chilli is perishable and wasted due to poor post harvest handling and processing facilities. Blanching is carried out to inactivate natural enzymes in order to improve color and texture of the product. Blanching has been found to enhance the drying rate of chilli due to cell wall destruction (Turhan, Turhan & Sahbaz, 1997). Dried chilli powder is the most widely used condiment for flavouring and colouring in Asian cuisines (Toontom, Meenune, & Posri, 2010). Chilli powder is prepared from ripe chilli and it is dried to make chilli powder and to store it for both short and long term storage (Hossain & Bala, 2007). Drying is a process of removes moisture by heat. It is one of the oldest methods of food preservation. Drying is the most widely used in food preservation (Gupta, Ahmed, Shivare & Raghavan, 2002). It is essential to reduce the moisture content of chilli after harvesting to prevent the development of micro-flora and loss of quality (Satishkumar, Karthik & Basamma, 2015). The traditional drying method is sun drying. Sun drying requires 7-20 days to reduce the moisture content to 10-15% in chilli depending on the weather condition (Hossain, 2003) and it is a lengthy process, taking up to 4-10 days to bring moisture content to 9.9 % wet basis (Oberoi, Ku, Kaur, & Baboo, 2005).

There are so many types of drying of chilli such as traditional sun drying, improved sun drying, solar drying and hot air oven drying etc. Traditional drying method is sun drying and is known to be associated with microbial proliferation and quality deterioration in red pepper (Condori, Echazu & Saravia, 2001). Solar drying is a cheap method with abundant renewable energy source. It is also an environmental friendly and economical drying method for rural farmers (Basunia & Abe, 2001). It is more convenient for rural and other areas with scarce or irregular electricity supply. Solar drying is a good alternative for sun drying for the production of high quality dried products (Saleh & Bardran, 2009). Hot air drying is popular method because drying time is short, uniform heating and hygienic characteristics. The temperature for this method ranges from 45 to 70ºC (approximately 10% of moisture content), and takes about 20 hours (Diaz-Maroto, Perez-Coello, Vinas & Cabezudo, 2003). There is always a tendency towards the use of improved drying methods which require low energy for more rapid with uniform drying to produce and hygienic product.

There are many chilli powder enterprises in Myanmar and many kinds of spices powder with various brands to be seen in local market. Most of spices powder production in Myanmar has poor quality and poor hygiene in the local market. The carcinogenic dyes are often used to brighten the colour of produce, making it more attractive to consumers. Additionally, food contamination of mycotoxin occurs in red pepper due to improper drying method and excess amount of moisture content in the dried chilli. In Mandalay Region and Shan State, the chilli are placed and spread on plastic or bamboo mats on the floor in front of farmers' houses for drying. The drying of chilli on the open floor is not proper method for food safety. The chilli may be contaminated by through livestock, humans and dust cannot be avoided and fungal growth cannot be controlled. This causes problems with aflatoxins in later (Ko Lwin, Garcia & Vitoria, 2015).

The quality of dried chilli is determined by various parameters such as colour, ascorbic acid content, capsaicin content and aflatoxin content (Wang, Xia, Wang, Luo, & Huang, 2009). In order to prevent fungal proliferation and improve the quality of paprika, different drying methods have been employed. Since dried chilli is susceptible to fungal proliferation, the conventional drying method causes favorable conditions for mycotoxin contamination (Bircan, 2005). Aflatoxins are highly toxic product of mould which is the mainly create problems in liver and kidney causing toxicity and carcinogenicity in human being (Ayub & Sachan, 1997). The European

Commission (EC, 2006b) reported that the maximum permitted levels of total aflatoxins was 10 ng/g and aflatoxin B1 was 5 ng/g respectively for spices (MOH, 2006). To prevent fungal growth and improve the quality of chilli, different drying methods have been employed in the processing of dried chilli. Besides, the increasing demand for high-quality shelf-stable dried products requires the optimization of the drying process conditions, especially temperature, with the purpose of accomplishing not only the efficiency of the process but also the final quality of the dried product (Di Scala & Crapiste, 2008).

According to the above-mentioned problems, this study was focused on the drying technique useful for farmers and small scale producers. The study was carried out with the following objectives:

1. to find out the optimum drying temperature of chilli in oven drying
2. to study the effect of open sun and solar tunnel drying methods on quality of dried chilli

CHAPTER II
LITERATURE REVIEW

Drying chili is an ideal way to preserve an abundant harvest or leftover supply for future use. Dried chilies are very versatile, and they can be ground into powders, or rehydrated to use in sauce and soups with an additional way to utilize this incredible vegetable. Drying properly depends upon several conditions, such as airflow, weather, and humidity levels (Gupta, 2016).Drying is a method of food processing and removal of moisture by heat. It is one of the oldest traditional methods of food preservation, which provides long shelf-life, light weight and less space for transportation and storage. The advantages of dried products are the weight and volume of dried products are reduced and it can decrease the cost of packaging, handling, storage and transportation (Ertekin & Yaldiz, 2004). For drying of red chilli, good quality, ripened one with no defects and damage or decay are collected. Chilli with less quality is excellent for chutneys and pickles, but they may not survive the drying process. Any variety of chilli can be used for drying, but the larger the fruit, the longer the drying process will take and the greater the risk of spoilage (Gupta, 2016).

After drying, chilli retains nutritive value but some of the nutrients are lost during drying at high temperature. Some mechanical and solar driers are being used for drying to reduce the drying period. At high temperature, the drying period is reduced; however, drying of chilli may cause losses of volatile compounds, nutrients, color resulting in low quality of the product at very high temperature (Ertekin & Yaldiz, 2004).The moisture content of red chilli is 70-80 % (wb) at harvest time. It is very susceptible to insect attack and fungal infection during storage. It is needed to reduce their moisture by drying and dehydration for increasing the shelf life. Excess moisture takes a long time in drying; it encourages the growth of microorganism and loss of quality during storage (Hossain, Hossain, Awal, Alam & Rabbani, 2015).

2.1 Effect of Blanching Practice on Drying

Blanching is a thermal treatment that is usually performed prior to food processes such as drying, freezing, frying, and canning. Blanching involves heating vegetables and fruits rapidly to a predetermined temperature and maintaining it for a specified amount of time, typically 1 to less than 10 minutes. Blanching has several advantages as it reduces drying time, inactivates the enzyme that bring undesirable changes, expulses air from the tissue and retains minerals and acids (Cruess, 1997).

Various pretreatments including blanching (as hot water and steam), osmotic dehydration and usage of chemical agents (potassium metabisulphate, potassium and sodium hydroxide, potassium carbonate, methyl and ethyl ester, citric acid and ascorbic acid) have been a number of pretreatments practiced in food drying. Blanching inactivates the enzymes (responsible for creating off-flavors in food), increases drying rate and fabricates the final product with desire quality (Tavakolipour & Mokhtarian, 2015).

Pretreatment of crop before dehydration improves the drying process as well as the quality of the dried product. Blanching is one of the pretreatment methods that are used to arrest some physiological processes before drying. It is heat pretreatment that inactivates enzymes that cause deterioration in food. It also destroys some micro - organisms that cause food deterioration and thus reducing their population (Breidt, Hayes & Fleming, 2000). The dried products are generally stored for periods between one month and 18 months to enhance food security. Farmers have reported deterioration of crops during storage such as discoloration but the stability of nutrients during drying and storage (Saka, Rapp, Ndolo, Mhango & Akinnifesi, 2007).

The advantages of blanching are enhancing drying rate and product quality, decreasing microbial load, removing pesticide and toxic residues, increasing extraction of bioactive compounds, surface cleaning, removing damaged seeds or foreign materials, killing parasites and their eggs, and reducing oil uptake.The blanching treatment could enhance the drying rate and that would help reduce energy consumption during the drying process. Generally, blanching treatment can inhibit various undesirable enzymatic reactions and thus may be required to improve the final quality of the processed product (Nilnakara, Chiewchan & Devahastin, 2009). In addition, blanching pretreatments naturally enhance the drying rates of cabbage (Watanabe et al., 2014).

These reasons are as follows: the water permeability of the surface is enhanced due to decreased hardening of the sample surface (Orikasa, Wu, Shina, & Tagawa, 2008) internal resistance to moisture diffusion is reduced by changes in the microstructure due to physical damage to the sample (Watanabe et al., 2014), and internal water permeability is improved due to damage to the cell membranes by heat stress (Ando et al., 2016). These factors interact in a complicated manner to enhance the drying rate.

In chilli, vitamin C content was retained in blanched (at 90ºC for 3 minutes) samples rather than the non-blanched samples. The color value of blanched and non blanched sample was not significantly different. Moreover, the chilli samples pretreated with water blanching and air dried at 75ºC had the highest and significant amount of shrinkage while sun dried chilli had the lowest shrinkage value (Tavakplipour & Mokhtarian, 2015).

The drying rate for yam samples blanched at temperature of 80ºC and 90ºC are not significantly different. Drying rate for 30 minutes blanched sample was initially lower than others due to the soaking period (Oyewole & Olaoye, 2013). The drying rates for unblanched bell pepper were lower than that of other samples. The drying rates for steam blanched and water blanched samples were higher than that of the integrated use of oil and water blanching methods (Akintunde & Fagbeja, 2011).

Blanching has no effect on the drying rate of potatoes which could be due to the gelatinization of starch during blanching. Blanching treatment did not differ in drying time when compared with blanched treatment or control samples. Besides, blanching time has no effect on the drying rate and drying time in all potato samples (Agarry, Durojaiye & Afolabi, 2005).

2.3 Drying Characteristics of Chilli

Drying is one of the most widely used methods for preserving agricultural products or food. The main purpose of drying agricultural products is to reduce their water content for minimizing microbial spoilage and deterioration reaction during storage (Lee et al., 2016). Among the processing methods, drying is reliable and efficient for preserving agricultural products for further processing. The removal of moisture content from agricultural products during drying can reduce moisture-mediated degradation and chemical and enzymatic reactions.

Dried products are popular owing to their longer shelf-life, produce diversity, and remarkable reduction in volume. In addition, consumers prefer high-quality dried products that retain nutritional and health benefits. Because the majority of agricultural products are thermo-sensitive, their color and chemical and physical properties may change significantly because of excessive heat accumulation during drying. Therefore, temperature control during drying is crucial to obtain high-quality dried products (Lee et al., 2016).

A total drying time of 30 hours was required for chilli drying in farm solar dryer to reduce the moisture content from 76.5 % (w.b) to about 9.0 % (w.b). Total drying time of 48 hours for open sun drying for the same level of moisture contents which farm solar dryer was shorter drying time than open sun drying Thus, the higher temperature was obtained in farm solar dryer over the ambient temperature. The mechanical dried chilli was lower moisture content than improved sun dried chilli followed by the sun dried chilli (Desai, Vijaykumar & Anantachar, 2009).

In sun drying with shelves, it is required 33 hours for whole chilli and 30 hours for slit chilli to reach the equilibrium moisture content. Whole chilli samples were taken longer drying time compared with slit chilli samples in all drying techniques. Mechanical dried chilli samples were taken less drying time than sun dried with shelves followed by the sun dried chilli on the floor (Shuchi, Sharma, Mittal, Jindal & Gupta, 2017). Drying temperature and drying rate were varied from one to three times depending upon the physical treatment and drying temperature (Toontom, Meenune, Posri & Lertsiri, 2012.)

2.4 Effect of Drying and Drying Methods on Physical and Chemical Characteristics of Dried Chilli

Chilli (*Capiscum annum*) is an important vegetable crop because it provides an abundant and cheap source of vitamins, minerals and fibre. It is also highly rich in ascorbic acid. Chilli deteriorates fast after few days of harvest due to its high moisture content. The most common method of preservation for chilli is by drying which is an energy-intensive process. The main objective for drying is the reduction of the moisture content to a level, which allows safe storage over an extended period thus extending the shelf-life (Ajaykumar, Sandeep & Madhukar, 2012).

Drying is carried out traditionally by sun-drying because it is a cheap, simple method that needs low capital investments. The main disadvantages of sun-drying are tedious, long drying time and subject to changes in weather conditions**.** The use of alternative drying methods such as industrial drying methods (hot-air and solar drying) to replace the traditional sun-drying technique has been observed to help overcome the disadvantages. More advantages of dried products are reduced bulk, and hence are easier to transport and package (Akintunde & Fagbeja, 2011).The drying method can affect the nutritional content of the finished product, although product deterioration is usually due to the application of excess heat, rather than the moisture removal. There are several factors influencing the physical and chemical quality parameters of dried chilli. Some chemical and biochemical reactions such as browning reactions and lipid oxidation might alter the final color (Okos, Campanella, Narsimhan, Singh & Weitnauer, 2007). Drying conditions and physico-chemical changes that occur during drying and rehydration processes seem to affect the quality properties of the rehydrated products (Rudra, Singh, Basu & Shivhar, 2008)

Drying types can be classified by either the mechanism of heating or mechanism of vapour transport. Traditional drying methods, including hot-air drying, can cause many undesirable changes in plant materials that affect the quality of final products, such as excessive shrinkage, discoloration, oxidation of functional ingredients, and severe deterioration of nutritional and sensorial properties (Hebbar, Vishwanathan & Ramesh, 2004).Hot air drying requires a high temperature which supplies the heat and removes the water vapor whereas vacuum drying uses a reduction in pressure to remove the vapour (Morris, Barnett & Burrows, 2004). Hot-air drying is a simple method commonly used for fruits and vegetables. Some disadvantages of hot-air drying regarding the drying process parameters include low energy efficiency and the lengthy drying times required during the falling rate period (Bazyma et al., 2006).

Direct solar drying requires an area with a large, open space and long drying times. It is highly dependent on the availability of sunshine and is susceptible to contamination of insect, pests, fungi, microorganisms and dust. Most agricultural products require drying process in an effort to preserve the quality of the final product. The drying process requires high heat to vaporize in the material, but the use of high heat also affects loss of color, aroma and vitamins in products (Nagaya et al., 2006).Open sun drying is the most common method of crop drying in developing countries. Despite several disadvantages, it is widely practiced because it is simple way of drying. Sun drying is still used to preserve the chilli but unprotected from rain, wind-born dirt and dust, infestation by insects, rodents and other animals. These dried products may be seriously degraded to some extent and become inedible and resulted food quality loss for domestics and international markets due to unsafely aspects. (Madhlopa, Jones & Kalenga, 2002).The solar dryer can be a good alternative to mechanical dryer in regions with stable warm and sunny weather. Especially in areas with no access to electricity, or unstable power supply, this could be an important method for preserving food. Compared to primitive sun drying, the advantages are protection from unstable weather conditions, no direct sun exposure and protection from animals, insects and birds. A solar dryer will also dry the products in a shorter time, because of collection of heat from the sun, which gives less time for microorganisms to establish and grow. The fact that the process is environmental friendly, because no fossil fuel is used makes it even a better method in the future (Sharma, Chen & Vu Lan, 2009). Solar drying is the promising alternative for chilli drying in developing countries because mechanical drying is mainly used in industrial countries and is not applicable to small farms due to high investment and operating costs (Muhlbauer, Esper & Muller, 1993).

The open yard sun dried chilli samples were higher titrable acidity content than solar tunnel drying method. Solar tunnel dried samples had higher the lightness and redness value than the open yard sun dried samples. Solar tunnel dried samples had more retention of ascorbic acid content than open yard sun dried samples. The capsaicin content of dried chilli in solar tunnel was more than the chilli dried under open yard sun drying. It was concluded that solar tunnel drying method gave better quality than open yard sun drying method and solar tunnel dryer saved drying time over the open yard sun drying (Manjula & Ramachandra, 2014).

The maximum temperature inside the solar tunnel dryer had higher than t drying at ambient temperature. Solar tunnel dryer required 24 hours to reduce the moisture content from 75% to 5% when the total drying time of 40 hours required for open sun drying to get the same moisture content level (Dhanore & Jibhakate, 2014).
Reducing sugar levels were not significantly different in all drying methods but fresh chilli had higher level than all dried samples. The drying air temperature of 60ºC were retained the phenolic compounds compared with other samples. The total phenolic compounds decrease in all treatments over the fresh chilli. In sun drying method, loss of ascorbic acid was due to direct exposed to sun light (Wiriya, Paiboon & Somchart, 2009). The capsaicin content of dried chilli from all the drying methods was higher than the fresh chilli. Hot air dried chilli had the highest capsaicin content compared with freeze dried and sun dried chilli. Freeze dried chilli had high colour values and ascorbic acid content than other drying methods. Sun dried chilli was the least in all physical and chemical qualities with the highest colour degradation followed by hot air dried sample (Toontom, Meenune, Posri & Lertsiri, 2012). According to Simal,

Dey and Rosell (1997), the most important reasons of dried products were longer shelf-life, product diversification as well as substantial volume reduction to decrease transportation cost. This could be further expanded by improvements in product quality and process applications.

2.5 Effect of Water Activity and Moisture Content of Dried Chilli

Water activity is an important factor in food production which is related to physico-chemical deterioration reactions and microbiological stability. Besides, water is the main component of a foodstuff, which also contains proteins, fats, carbohydrates and mineral salts. Food materials changed in chemical reaction, physico-chemical changes and microbial growth during processing which are affected by the amount of available water or water activity. Water activity is one of the major effect to loss of food stability during storage because of the availability of water promotes the microbial growth and chemical reaction. The water activity is an important factor affecting product stability. The water activity enhanced the non-enzymatic browning reaction during storage (Kwanhathai, Duenchay, & Rungnaphar 2012).

Pathogenic microorganisms cannot grow at below 0.62 of water activity. Water activity of a sample at 0.3, the product is most stable in enzyme activity, lipid oxidation, non-enzymatic browning, and microbial growth. If a product of water activity was increased, the probability of the food product was increased deterioration (Gustavo, Anthony, Shelly & Theodore, 2007).Water activity of control chill samples (0.152) was the highest followed by the sample treated with sulphited (0.145) and the lowest water activity of (0.143) was in blanched samples It was showed that microbial growth will be less in blanched sample as compared to others samples (Bakane, Khedkar, Wankhadea & Kolhe, 2014). Water activity reduced beyond the limit which results loss of vitamins such as C, E, B_1 etc (Suryawanshi, 2018).

The rate of the chemical reaction and microbial growth depend on the water activity level. Browning reaction may be high when water activity ranges from 0.6 to 0.7. Water activity is lower than 0.75 that inhibit the microbial growth but yeast and molds can grow. At a particular condition of temperature and moisture, the interactions between these components can cause browning and lipid oxidation that can provide the favorable conditions for microbiological growth (Khalloufi, Glasson & Ratti, 2000).

CHAPTER III

MATERIALS AND METHODS

3.1 Experimental Site and Period

The experiment on drying methods was conducted at Postharvest Research Institute (PHRI), Department of Agriculture, Nay Pyi Taw from April to May in 2019. The measurements and quality evaluation were carried out at the Division of Postharvest Technology, Advanced Centre for Agricultural Research and Education (ACARE), Yezin Agricultural University (YAU).

3.2 Experimental Material

Fresh red chilli of cv. Champion 777, collected from Nyaungdon Township, Ayeyarwaddy Division, was used as tested cultivar. It took 10 hours by bus from the farm to experimental site.

The partially red, green, infected and defected irregular shape fresh chilli were separated and discarded. The uniform fresh red chilli fruits were selected for drying processes. The samples were cleaned by vegetable washing machine (Plate 1) and they were surface dried for 7- 8 hours by the removal of surface moisture. The total of 100 kg sample chilli was collected for drying using three different drying methods of open sun drying, solar tunnel and hot air oven drying. In the first experiment, 60 kg of fresh red chilli was selected and divided into two groups consisting of 30 kg for each pretreatment such as blanching and non-blanching treatment. The sample of 10 kg chilli was dried for each drying method at 50ºC, 60ºC and 70ºC.

In the second experiment, fresh red chilli of 40 kg were selected and divided into two groups consisting of 20 kg for blanching and non-blanching. The sample 10 kg chilli was dried for each drying method of open sun drying and solar tunnel drying. Blanching of chilli was done with hot water at 90ºC for 3 minutes (Plate 2) by the method of Ajaykumar, Sandeep & Madhukar (2012)

3.3 Experimental Design

Experiment I

The first experiment was factorial arrangement in completely randomized design (CRD) with three replications. The treatment combinations were as follows.

Factor (A) Pretreatment

- Blanching
- Non-blanching

Factor (B) Drying temperature

- Hot air oven drying at 50ºC
- Hot air oven drying at 60ºC
- Hot air oven drying at 70ºC

Hot Air Oven Drying

Hot air oven drying was conducted with air oven model KED- S24D2 at different temperatures of 50ºC, 60ºC and 70ºC. The samples of blanched and non blanched chilli were placed on aluminum perforated trays which were dried by the hot air oven (Plate 3).Weight of samples was recorded before and measured at every 1 hour till to reach equilibrium moisture content. The duration time for hot air oven drying was recorded along the drying process.

Experiment II

The second experiment was arranged in factorial completely randomized design (CRD) with four replications. The treatment combinations were as follows.

Factor (A) Pretreatment

- Blanching
- Non-blanching

Factor (B) Drying method

- Open sun drying
- Solar tunnel drying

Open Sun Drying

The open sun drying was conducted under sun shine in the second week of April. . The samples of blanched and non blanched chilli were placed on aluminum perforated trays and dried by using wooden shelf of open sun drying (Plate 4). Weight of samples was recorded beforehand and measured the weight at every 1 hour till to reach equilibrium moisture content. The duration of drying time, relative humidity and ambient temperature were daily recorded during drying process from 9:00 am to 5:00 pm.

Solar Tunnel Drying

The solar tunnel drying was carried out under sun using artificial drying structure. The blanched and non-blanched samples were dried on perforated mess in the solar tunnel under the sun (Plate 5). Weight of samples was recorded at every 1 hour intervals. Drying was carried out continuously till equilibrium moisture content was reached. The duration of drying time, relative humidity and ambient temperature were daily recorded during drying process from 9:00 am to 5:00 pm.

Preparation of the Solar Tunnel Dryer

The solar tunnel dryer was constructed with PVC pipe, woods, nylon mesh, metal mesh and transparent plastic sheet etc. The frame size of the solar tunnel dryer was 3 m length x 1 m width x 1.2 m height. There are 4 wooden trays with metal mesh screen painted with black color paint. The transparent plastic sheet was used to cover the drying chamber. There are six holes at the upper side of the plastic sheet for air outlet and these holes were covered with nylon mesh. During drying period, the minimum temperature was 48ºC and the maximum temperature was 67ºC inside the solar tunnel dryer for a day.

3.4 Collected Data

From each treatment, blanched and non-blanched dried chilli were used to assess the quality data on the drying hour, drying rate, moisture content, water activity, colour difference, browning index, ascorbic acid and microbial load (aflatoxin content).

3.4.1 Determination of moisture content

Blanched and non-blanched chilli were dried by open-sun-drying, solar tunnel drying and hot air oven drying up to equilibrium moisture content. The initial moisture content of fresh red chilli was determined by standard gravimetric method (AOAC 2000). Weight of sample was at regular intervals by electronic weight balance to determine moisture content of the samples and the drying rate. At the end of the drying period, the final moisture content and drying rate were calculated as follows:

$$M=\frac{\text{Initial weight-Final weight}}{\text{Initial}}\times 100$$

Where, M= Moisture content (% wb)

$$D=\frac{(M_1 - M_2)}{(T_2\text{-}T_1)}$$

Where, D = Drying rate (% wb), M_1 = Moisture content (% wb) at Time T_1 (h) and M_2 = Moisture content at Time T_2 (h).

3.4.2 Determination of color

The color of fresh chilli and dried chilli pods were measured using a colorimeter (Mini Scan XE Plus, Hunter Lab, USA). Color was expressed as L^* (whiteness to brightness), a^* (redness to greenness) and b^* (yellowness to blueness). The sample was measured three times at three different positions (the base, the middle and tip portions). Total color changes (ΔE) and browning index (BI) were calculated using following equations:

$$(\Delta E)=\sqrt{\left(L^*\text{-}L_0^*\right)^2+\left(a^*\text{-}a_0^*\right)^2\left(b^*\text{-}b_0^*\right)^2}$$

$$BI=\frac{[100(x\text{-}0.31)]}{0.17}$$

$$x=\frac{(a^*+1.75L^*)}{(5.645L^*+a^*\text{-}3.012b^*)}$$

Where L^*_0 , a^*_0 and b^*_0 are initial color of chilli samples;

3.4.3 Determination of water activity

Water activity of fresh chilli and dried chilli were measured three times for a sample to get a mean value using water activity meter (AquaLab 4TE) calibrated as a standard sample with a known value (Plate 6).

3.4.4 Determination of ascorbic acid

Ascorbic acid content of fresh chilli and dried chilli was determined by titremetric method (AOAC 1990). Ascorbic acid content was described as mg per 100 g. Two grams of dried chilli was taken and extracted with 3% metaphosphoric acid solution and made up to a volume of 150 ml. This solution was filtered through Whatman No.1 filter paper. The dye factor was calculated by titrating ascorbic acid standard solution with 2,6- dichlorophenol indophenols dye solution. The ascorbic acid content was calculated by titratiing again sample filtrate of 20 ml with 2,6-

dichlorophenol indophenols dye solution. Turning to pink colour is the end point. Ascorbic acid content was calculated by using the following formula;

$$\text{Ascoribic acid (mg/100g)} = \frac{\text{Titre value (ml)} \times \text{Dye factor} \times \text{volume makeup (ml)} \times 100}{\text{Volume of filtrated solution taken (ml)} \times \text{weight of sample}}$$

3.4.6 Determination of microbial load (Aflatoxin content)

Total aflatoxin content was measured by high performance liquid chromatography (HPLC) using the modified ISO 16050 at Agricultural Products Analytical Laboratory, Plant Protection Division under Department of Agriculture, Insein Township, Yangon Region and described as parts per billion (ppb).

3.4.7 Statistical Analysis

Analysis of variance and mean comparison were calculated with statistical package (Statistix version 8). The treatment means were compared by using the least significant difference (LSD) test at 5% level.

Plate 1 Washing of the chilli samples with washing machine

Plate 2 Preparation of chilli blanching at 90ºC of hot water for 3 minutes

Plate 3 Hot air oven drying of blanched and non-blanched chilli

Plate 4 Open sun drying of blanched and non-blanched chilli

Plate 5 Solar tunnel drying of blanched and non-blanched chilli

Plate 6 Measuring the water activity of chilli

Plate 7 Determination of ascorbic acid content

CHAPTER IV
RESULTS AND DISCUSSION

The experiment was conducted to study the effect of different drying temperatures and different drying methods on the drying characteristics and the quality dried chilli. In this experiment, different drying methods were compared on the drying characteristics. Optimum temperature of oven drying were determined with respect to moisture content, water activity, color difference, browning index, ascorbic acid content and aflatoxin content of dried chilli.

4.1 Drying Behavior

The decreasing moisture content with time for red chilli in all drying methods was described in Table 4.1 and 4.2. Open sun drying, solar tunnel drying and hot air oven dying (50ºC, 60ºC and 70ºC) of blanched (at 90ºC for 3 minutes) and non-blanched chilli were carried out. The initial moisture content of fresh chilli was 74% w.b and chilli was dried until the equilibrium moisture content was reached. It is evident from the data presented in that moisture content of chilli decreased with the increased in drying time in all drying methods.

4.1.1 Change in moisture content with time

The time required to reach the equilibrium moisture content were 27, 17 and 11 hours for blanched samples and 30,18 and 11 hours for non-blanched samples in the hot air oven drying at 50ºC, 60ºC and 70ºC, respectively. Non-blanched chilli took longer time to reach equilibrium moisture content as compared to the blanched chilli (Table 4.1). This is due to tissue of blanched chilli was partially cooked and the cell wall of chilli became soft, more permeable to moisture diffusion. According to this result, loss of moisture in blanched sample was faster as compared to non-blanched sample (Figure 4.1- 4.5). Hot air oven dried chilli at 70ºC took the minimum drying time to achieve the equilibrium moisture content, followed by the oven dried at 60ºC and 50ºC. Because higher the drying temperature, faster the drying rate takes place.

The time required to reach the equilibrium moisture content was 23 and 19 hours for blanched sample and 25 and 19 hours for non-blanched samples for open sun drying and solar tunnel drying respectively (Appendix 1). But in solar tunnel drying method, both blanched and non-blanched samples reached the equilibrium moisture content at the same time. The drying time during open sun drying and solar tunnel drying was recorded in sun shine hours. Temperature and relative humidity were recorded during drying for open sun and solar tunnel. The ambient temperature during drying period varied from a minimum of 36ºC to a maximum of 51ºC. The corresponding average temperature inside the solar tunnel dryer ranged from 48ºC to 67ºC. Relative humidity ranged from 11% to 30% for solar tunnel drying and 12% to 44% for open sun drying. The temperature in the solar tunnel was higher than the ambient temperature. This is due to the trapping of the more solar energy inside the solar tunnel dryer.

Table 4.3 presented the final moisture content of dried chilli as affected by different drying methods. The initial moisture content of fresh chilli was 74% (w.b). After drying, the final moisture content of dried chilli were ranged from 5.8% (w.b) to 7.3% (w.b) depending on drying method. The highest moisture content was observed in non-blanched samples with oven drying at 50ºC and open sun drying. The lowest moisture content was observed in blanched sample with oven dried at 70ºC. This was due to higher drying temperature which evaporated more water from the chilli.

4.1.2 Change in drying rate with time

The drying rate decreased with the duration of drying for chilli in all drying methods as shown in Table 4.4 and 4.5. According to the tables, the drying rate was decreased with increasing drying time. In all drying methods, the drying rates were higher in the early part of the drying process and the rate was gradually reduced during drying process due to decrease in moisture content.

In hot air oven drying at 60ºC and 70ºC, the drying rate of blanched and non-blanched samples were almost the same rate to reach equilibrium moisture content. But in these methods, drying rate of blanched sample was slightly higher than non-blanched samples at the beginning of the drying process (Figure 4.6 and 4.7).

Hot air oven dried at 70ºC had the maximum drying rate, followed by oven dried at 60ºC and 50ºC (Figure 4.5 to 4.7). In all drying methods, the drying rate was higher at the beginning of drying process. The rate was gradually decreased during the drying process due to less moisture content in the dried product. This finding was similar to Gupta et al., (2018) who also found that the rate was higher at the beginning of the process, then gradually reduced as the drying process progressed and the availability of moisture was reduced.

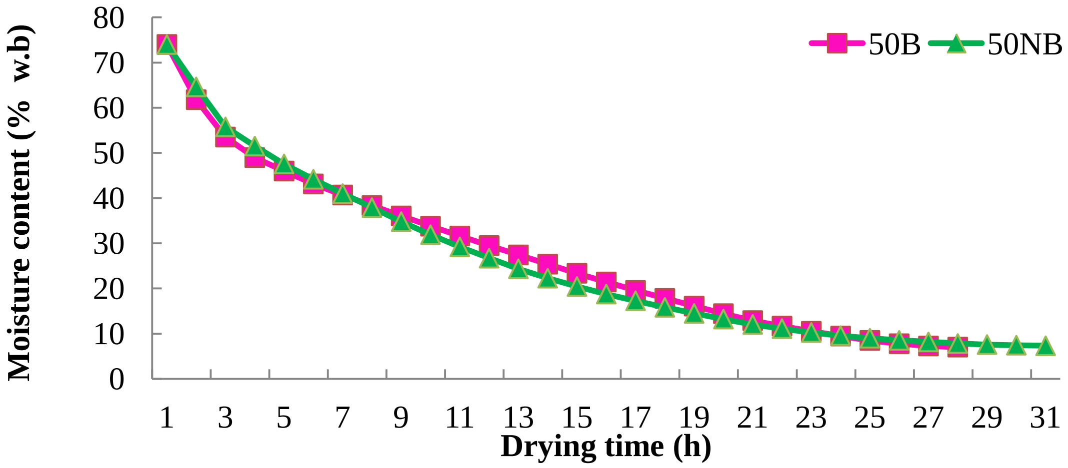
Open sun dried samples took longer drying time than solar tunnel dried samples. Hence, the drying rate of red chilli in the tunnel was found to be higher than open sun dried samples. In the open sun drying method, the drying rate of blanched sample was higher than non-blanched sample up to 4 hours. After that drying rate in both blanched and non-blanched samples showed similar rate during the drying process (Figure 4.8).

Table 4.1 Moisture content of chilli with time during hot air oven drying at 50ºC, 60ºC and 70ºC

Drying period (hours)	Moisture content (%w.b)					
	50ºC		60ºC		70ºC	
	Blanching	Non-blanching	Blanching	Non-blanching	Blanching	Non-blanching
0	74.00	74.00	74.00	74.00	74.00	74.00
1	61.78	64.60	57.92	58.93	54.93	57.20
2	53.51	55.75	45.55	46.92	37.80	41.76
3	48.96	51.51	35.20	36.11	24.15	29.29
4	46.00	47.56	31.21	26.60	15.49	20.16
5	43.14	44.16	28.00	22.30	12.15	17.73
6	40.69	41.00	24.83	20.14	9.86	15.38
7	38.35	37.89	21.74	18.15	8.26	13.16
8	36.05	34.81	18.80	16.26	7.16	11.08
9	33.78	31.92	16.28	14.39	6.33	9.17
10	31.61	29.20	14.06	12.99	6.04	7.48
11	29.49	26.71	12.20	11.76	5.76	6.01
12	27.43	24.36	10.50	10.60	-	-
13	25.38	22.28	9.24	9.45	-	-
14	23.37	20.45	8.22	8.49	-	-
15	21.44	18.77	7.43	7.75	-	-
16	19.57	17.29	6.90	7.26	-	-
17	17.80	15.83	6.63	7.01	-	-
18	16.10	14.49	-	6.76	-	-
19	14.43	13.24	-	-	-	-
20	12.89	12.05	-	-	-	-
21	11.68	11.12	-	-	-	-
22	10.53	10.27	-	-	-	-
23	9.47	9.58	-	-	-	-
24	8.51	9.00	-	-	-	-
25	7.77	8.53	-	-	-	-
26	7.28	8.17	-	-	-	-
27	7.03	7.84	-	-	-	-
28	-	7.60	-	-	-	-
29	-	7.45	-	-	-	-
30	-	7.33	-	-	-	-

Table 4.2 Moisture content of chilli with time during open sun drying and solar tunnel drying

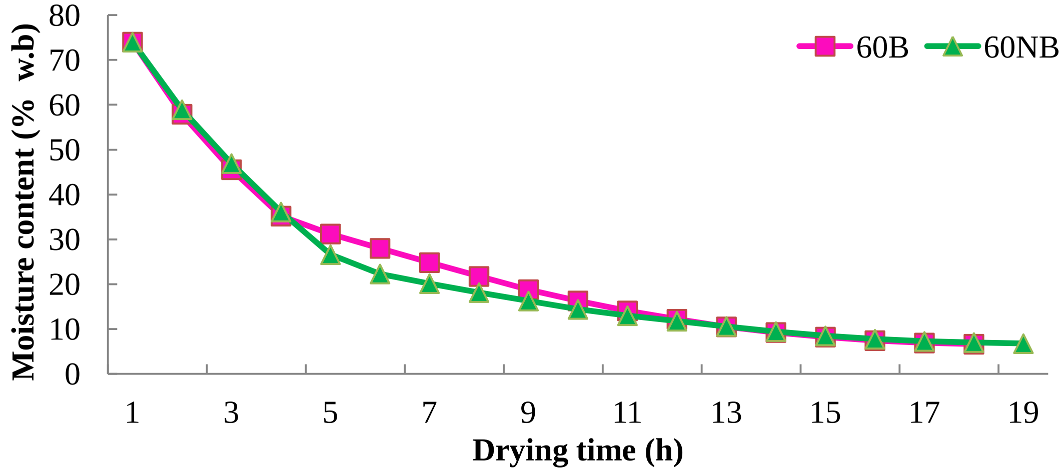
Drying period (hours)	Moisture content (% w.b)			
	Open sun drying		Solar tunnel drying	
	Blanching	Non-blanching	Blanching	Non-blanching
0	74.00	74.00	74.00	74.00
1	61.44	65.70	61.51	62.33
2	50.43	58.42	52.71	54.80
3	44.92	54.27	44.83	49.70
4	40.78	50.29	39.15	45.32
5	36.91	46.41	34.58	41.04
6	33.27	42.55	30.46	36.87
7	29.76	38.75	27.09	32.87
8	27.10	35.28	24.08	28.93
9	24.57	32.21	21.19	25.66
10	22.20	29.42	18.47	22.43
11	20.05	26.71	15.99	19.29
12	17.97	24.12	13.58	16.50
13	15.98	21.69	11.50	13.96
14	14.32	19.48	10.05	11.72
15	13.03	17.35	8.82	9.84
16	11.93	15.52	7.80	8.38
17	10.91	13.82	7.02	7.38
18	9.96	12.28	6.50	6.61
19	9.04	10.91	6.23	6.35
20	8.20	9.74	-	-
21	7.47	8.78	-	-
22	6.97	8.04	-	-
23	6.72	7.55	-	-
24	-	7.30	-	-
25	-	7.30	-	-



50B = hot air oven drying at 50ºC with blanching

50NB = hot air oven drying at 50ºC with non-blanching

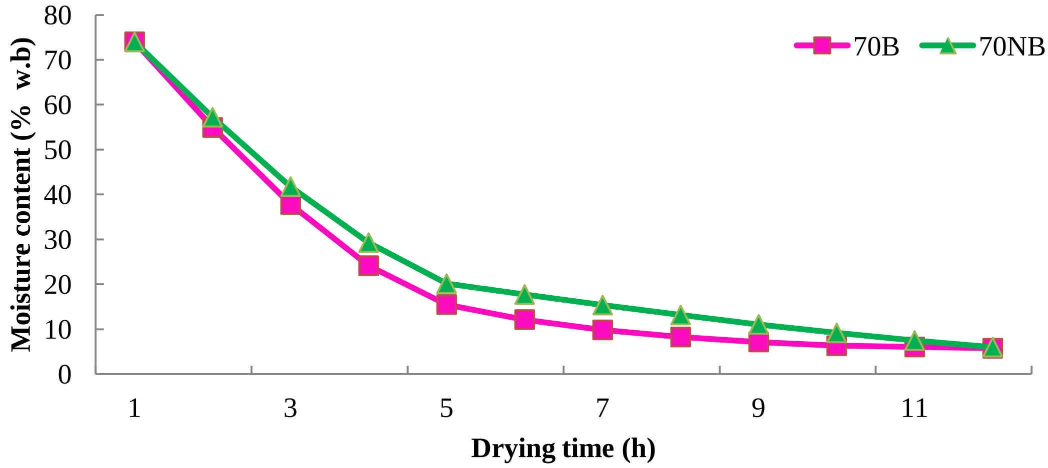
Figure 4.1 Decreasing of moisture content (% w.b) with time for chilli dried in hot air oven at 50ºC



60B = hot air oven drying at 60ºC with blanching

60NB = hot air oven drying at 60ºC with non-blanching

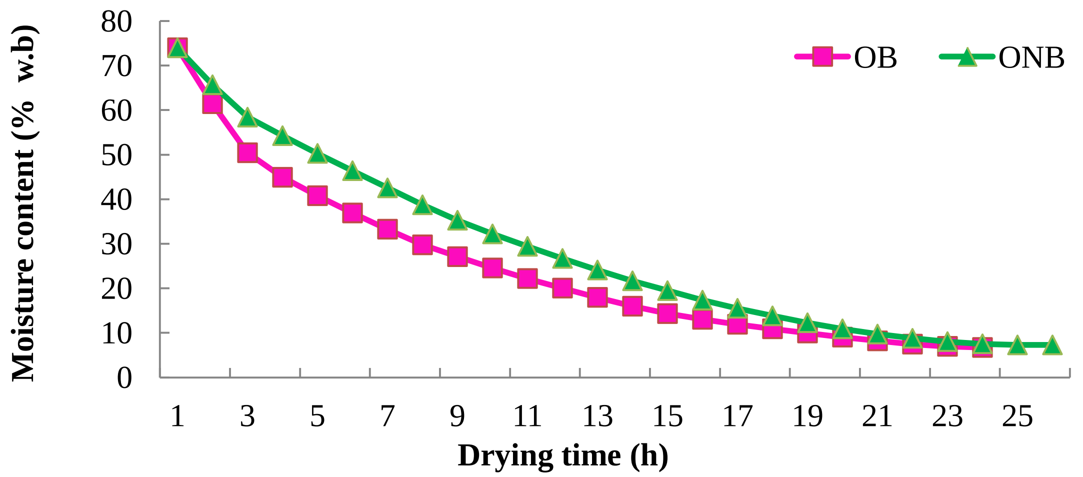
Figure 4.2 Decreasing of moisture content (% w.b) with time for chilli dried in hot air oven at 60ºC



70B = hot air oven drying at 70ºC with blanching

70NB = hot air oven drying at 70ºC with non-blanching

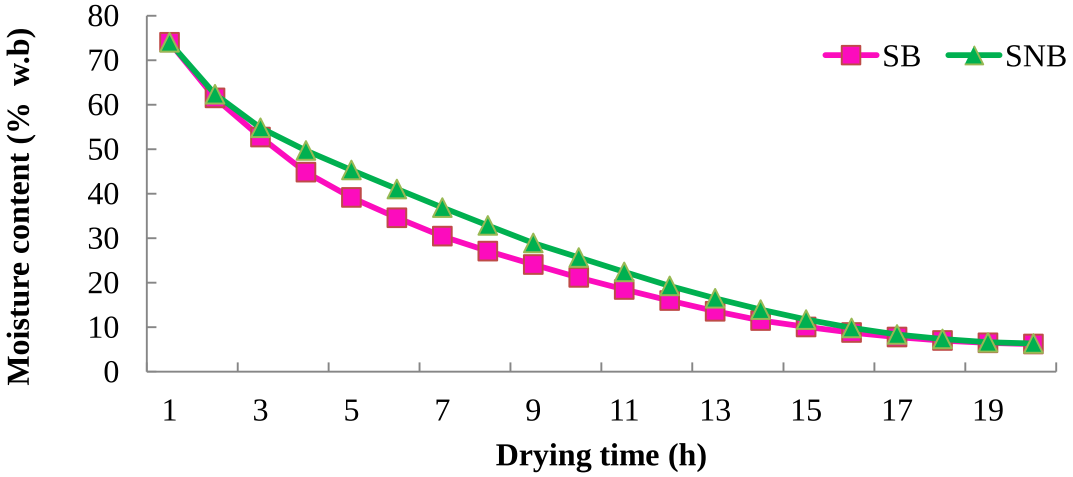
Figure 4.3 Decreasing of moisture content (% w.b) with time for chilli dried in hot air oven at 70ºC



OB = open sun drying with blanching

ONB = open sun drying with non-blanching

Figure 4.4 Decreasing of moisture content (% w.b) with time for chilli dried in open sun



SB = solar tunnel drying with blanching

SNB = solar tunnel drying with non-blanching

Figure 4.5 Decreasing of moisture content (% w.b) with time for chilli dried in solar tunnel

Table 4.3 Final moisture content of dried chilli as affected by different drying methods

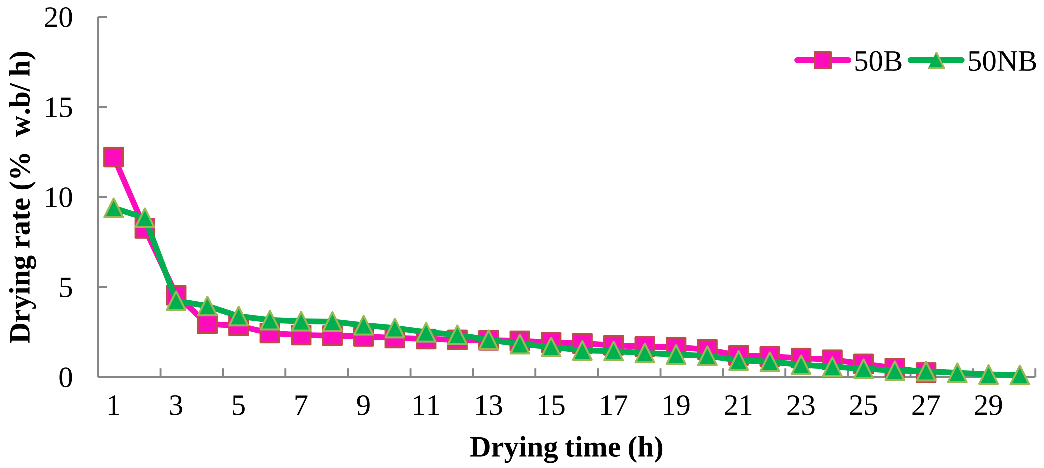
No.	Sample	Final moisture content (% w.b)
1	Hot air oven drying at 50ºC with blanching (50B)	7.0
2	Hot air oven drying at 50ºC with non-blanching (50NB)	7.3
3	Hot air oven drying at 60ºC with blanching (60B)	6.6
4	Hot air oven drying at 60ºC with non-blanching (60NB)	6.8
5	Hot air oven drying at 70ºC with blanching (70B)	5.8
6	Hot air oven drying at 70ºC with non-blanching (70NB)	6.0
7	Open sun drying with blanching (OB)	6.7
8	Open sun drying with non-blanching (ONB)	7.3
9	Solar tunnel drying with blanching (SB)	6.2
10	Solar tunnel drying with non-blanching (SNB)	6.4

Table 4.4 Drying rate of chilli with time during hot air oven drying at 50ºC, 60ºC and 70ºC

Drying period (hours)	Drying rate (% wb/h)					
	50ºC		60ºC		70ºC	
	Blanching	Non-Blanching	Blanching	Non-Blanching	Blanching	Non-Blanching
1	12.22	9.40	16.08	15.07	19.07	16.80
2	8.26	8.85	12.38	12.01	17.13	15.44
3	4.55	4.24	10.35	10.81	13.65	12.48
4	2.96	3.95	3.99	9.52	8.66	9.12
5	2.86	3.39	3.21	4.30	3.34	2.43
6	2.45	3.16	3.17	2.16	2.29	2.34
7	2.34	3.11	3.09	1.99	1.60	2.23
8	2.30	3.09	2.94	1.89	1.10	2.08
9	2.27	2.88	2.52	1.87	0.84	1.90
10	2.17	2.72	2.22	1.40	0.28	1.70
11	2.12	2.49	1.86	1.22	0.28	1.46
12	2.07	2.35	1.70	1.17	-	-
13	2.05	2.08	1.25	1.15	-	-
14	2.01	1.83	1.03	0.96	-	-
15	1.92	1.68	0.79	0.73	-	-
16	1.87	1.48	0.53	0.50	-	-
17	1.77	1.46	0.27	0.25	-	-
18	1.70	1.34	-	0.25	-	-
19	1.67	1.26	-	-	-	-
20	1.54	1.19	-	-	-	-
21	1.21	0.93	-	-	-	-
22	1.15	0.86	-	-	-	-
23	1.06	0.69	-	-	-	-
24	0.96	0.58	-	-	-	-
25	0.74	0.47	-	-	-	-
26	0.50	0.36	-	-	-	-
27	0.25	0.33	-	-	-	-
28	-	0.24	-	-	-	-
29	-	0.14	-	-	-	-
30	-	0.12	-	-	-	-

Table 4.5 Drying rate of chilli with time during open sun and solar tunnel drying

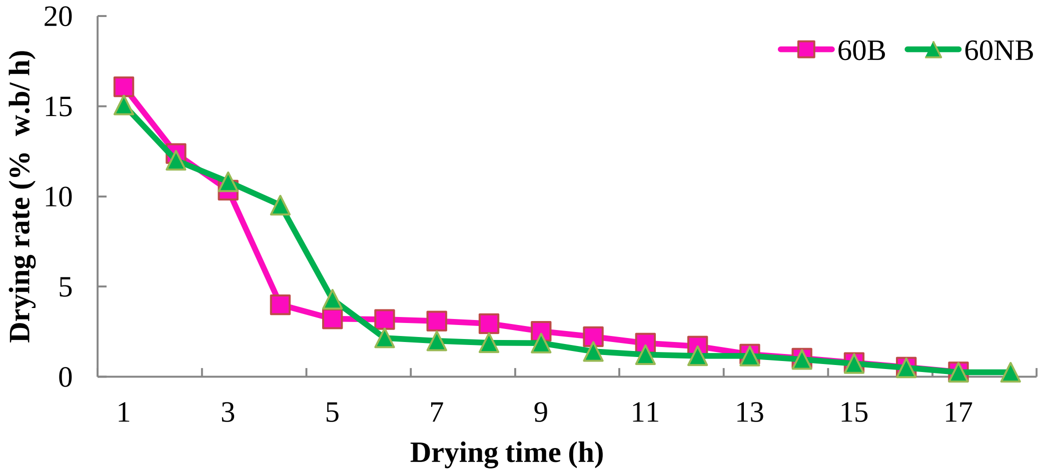
Drying period (hours)	Drying rate (% wb/h)			
	Open sun drying		Solar tunnel drying	
	Blanching	Non-Blanching	Blanching	Non-Blanching
1	12.56	8.30	12.49	11.67
2	11.02	7.28	8.80	7.53
3	5.51	4.16	7.88	5.10
4	4.14	3.98	5.68	4.38
5	3.88	3.88	4.57	4.28
6	3.64	3.86	4.12	4.17
7	3.51	3.80	3.37	4.00
8	2.66	3.47	3.01	3.94
9	2.54	3.07	2.89	3.27
10	2.37	2.79	2.72	3.23
11	2.15	2.71	2.48	3.14
12	2.08	2.59	2.41	2.78
13	1.99	2.43	2.08	2.54
14	1.66	2.21	1.44	2.24
15	1.29	2.13	1.24	1.88
16	1.10	1.83	1.02	1.46
17	1.02	1.70	0.78	1.00
18	0.95	1.54	0.53	0.77
19	0.92	1.37	0.26	0.26
20	0.84	1.17	-	-
21	0.73	0.96	-	-
22	0.50	0.73	-	-
23	0.25	0.50	-	-
24	-	0.25	-	-
25	-	0.00	-	-



50B = hot air oven drying at 50ºC with blanching

50NB = hot air oven drying at 50ºC with non-blanching

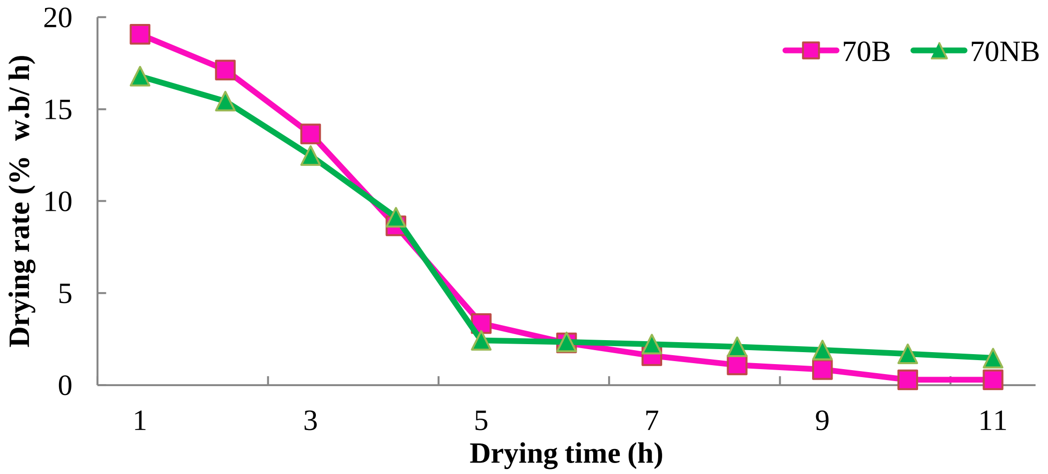
Figure 4.6 Decreasing of drying rate (% w.b/h) with time for chilli dried in hot air oven at 50ºC



60B = hot air oven drying at 60ºC with blanching

60NB = hot air oven drying at 60ºC with non-blanching

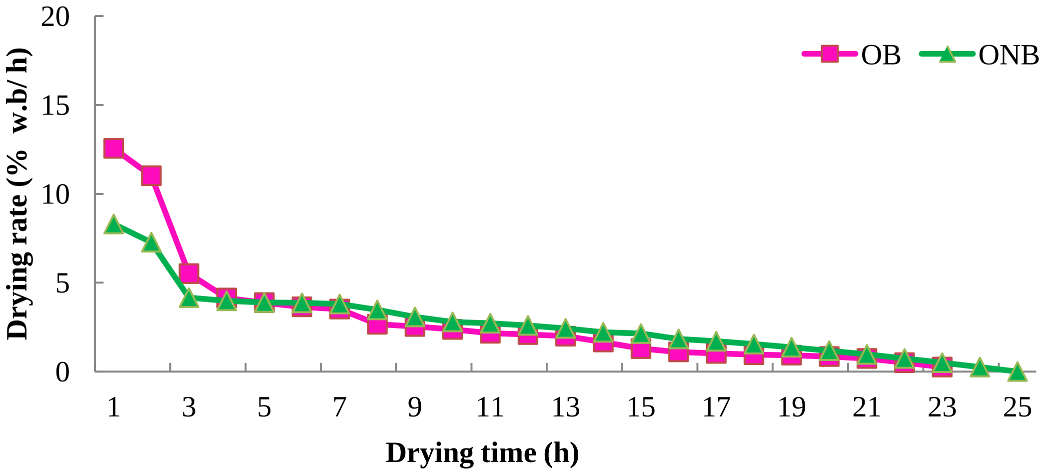
Figure 4.7 Decreasing of drying rate (% w.b/h) with time for chilli dried in hot air oven at 60ºC



70B = hot air oven drying at 70ºC with blanching

70NB = hot air oven drying at 70ºC with non-blanching

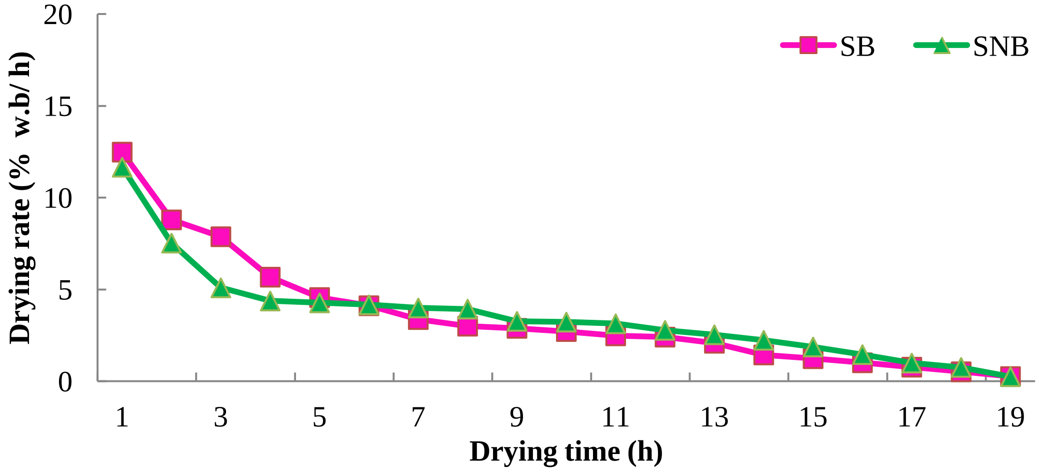
Figure 4.8 Decreasing of drying rate (% w.b/h) with time for chilli dried in hot air oven at 70ºC



OB = open sun drying with blanching

ONB = open sun drying with non-blanching

Figure 4.9 Decreasing of drying rate (% w.b/h) with time for chilli dried in open sun drying



SB = solar tunnel drying with blanching

SNB = solar tunnel drying with non-blanching

Figure 4.10 Decreasing of drying rate (% w.b/h) with time for chilli dried in solar tunnel drying

4.2 Effect of Different Oven Drying Temperatures on Quality of Dried Chilli

The quality parameters of dried chilli were observed in moisture content, water activity, colour difference, browning index, ascorbic acid content and aflatoxin content. The mean value of quality parameters as affected by different drying temperatures and pretreatment were shown in Table 4.6.

4.2.1 Effect of different oven drying temperatures on moisture content

Data presented in Figure 4.10 reveals the moisture content of chilli dried using hot air oven drying method at different drying temperatures of 50ºC, 60ºC and 70ºC with blanching and non-blanching treatments. The drying temperature at 70ºC showed significantly lower in moisture content (5.9% and 6.0%) compared to those at 60ºC (6.6% and 6.9%) and 50ºC (7.0% and 7.3%) for blanched and non-blanched samples respectively.

Attainment of optimum temperature at 70ºC resulted in high moisture loss with the lowest moisture content. Similar findings have been reported by Gupta (2016) who also found the lowest moisture content in the whole chilli dried at 70ºC compared to that at 60ºC and 50ºC**.** In this study, the moisture content was not significantly different between blanching and non-blanching treatments irrespective to drying temperatures. The interaction among different drying temperatures and pretreatment in moisture content was found to be non significant in this study.

4.2.2 Effect of different oven drying temperatures on water activity

Data presented in Figure 4.11 reveals the water activity of dried chilli using hot air oven drying method by different drying temperatures at 50ºC, 60ºC and 70ºC with blanching and non-blanching treatments. The drying temperature at 70ºC with blanched and non-blanched samples showed significantly low water activity (0.32and 0.31) compared to 60ºC (0.34) for blanched samples and 50ºC (0.36 and 0.35) for blanched and non-blanched samples.

Attainment of optimum temperature at 70ºC resulted in the lowest water activity. Non-blanching also exhibited considerably low water activity compared to blanched samples. Similar report has been reported by Toure (1985) who observed that unblanched samples had a lower water activity than blanched samples of dehydrated okra. There was no significant difference on the interaction effect among the temperatures with blanching and non-blanching.

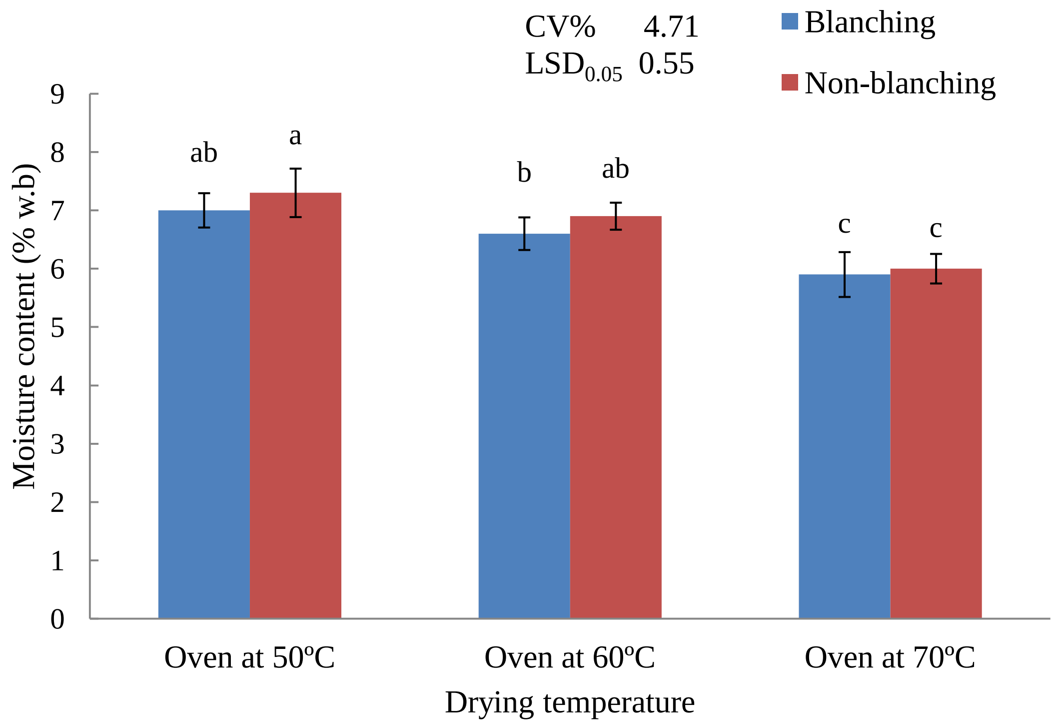


Figure 4.11 Effect of different drying temperatures and pretreatment on the moisture content (% w.b) of dried chilli

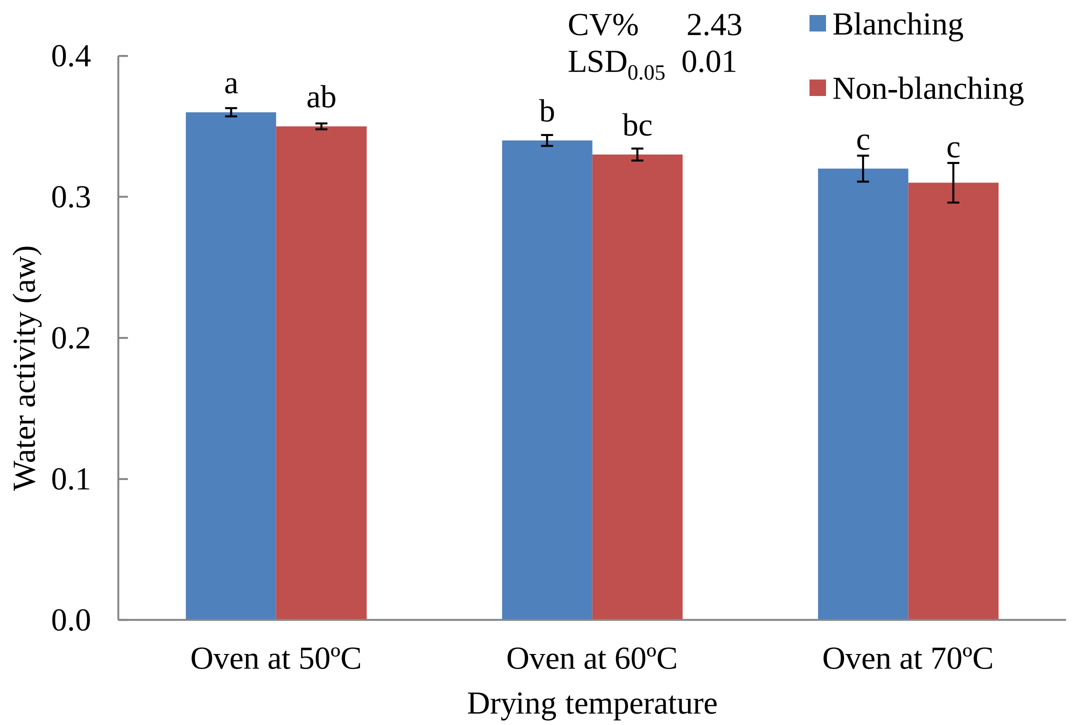


Figure 4.12 Effect of different drying temperatures and pretreatment on the water activity of dried chilli

4.2.3 Effect of different oven drying temperatures on color difference

Data presented in Figure 4.12 reveals the total color difference of chilli dried using hot air oven drying method by different drying temperatures at 50ºC, 60ºC and 70ºC with blanching and non-blanching treatments. The drying temperature at 70ºC showed significantly higher in color difference compared to 50ºC for non-blanched and blanched samples and 60ºC for blanched samples.

Attainment of optimum drying temperature at 50ºC resulted in low color difference. The lowest total color difference (ΔE) value was found in the chilli dried at 50ºC followed by the 60ºC and 70ºC. It may be related that higher drying temperature showed higher color change. Similar report has been reported by Saengrayap, Boonlap, & Boonsorn (2016) who observed high degradation of color of dried product when dried at high temperature. The data reveals no significant difference on the interaction effect between drying temperature and pretreatment

4.2.4 Effect of different oven drying temperatures on browning index

Data presented in Figure 4.13 reveals the browning index of chilli dried using hot air oven drying method by different drying temperatures at 50ºC, 60ºC and 70ºC with blanching and non-blanching treatments. The drying temperature at 70ºC showed significantly higher in browning index compared to 50ºC for non-blanched and blanched samples respectively.

Attainment of optimum drying temperature at 50ºC resulted in low browning index. The lowest browning index value was found in the chilli dried at 50ºC followed by the 60ºC and 70ºC. The browning index of dried chilli was influenced by high drying temperature. It may be due to high rate of millard reaction by sugar and amino acid in the chilli. This finding was similar to Lee, Chung, Kim & Yam (1991) who also reported high non-enzymatic browning in dried chilli due to a maillard reaction. When chilli dried at 70ºC, the browning index of blanched sample was lower than the non blanched sample. This may be due to proper inactivation of enzymes at higher temperature. Similar finding was reported by Saengrayap, Boonlap, & Boonsorn (2016) who observed lower browning index in chilli when blanched in hot water. There was interaction between different drying temperatures and pretreatment in browning index in this study.

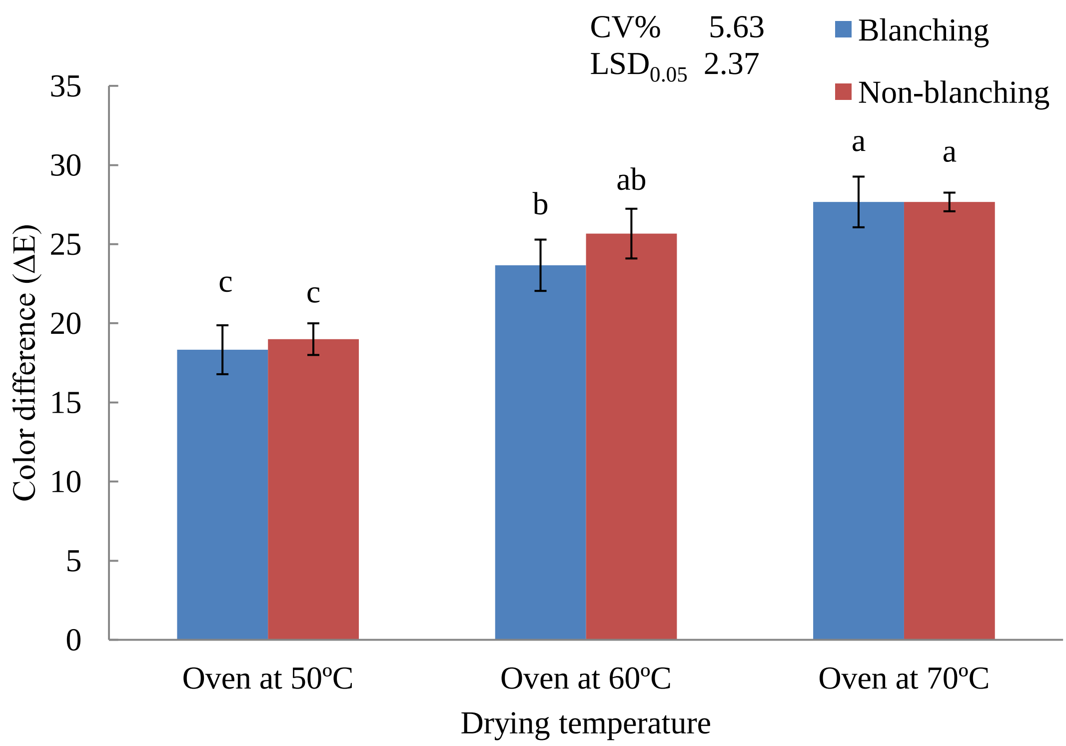


Figure 4.13 Effect of different drying temperatures and pretreatment on the color difference of dried chilli

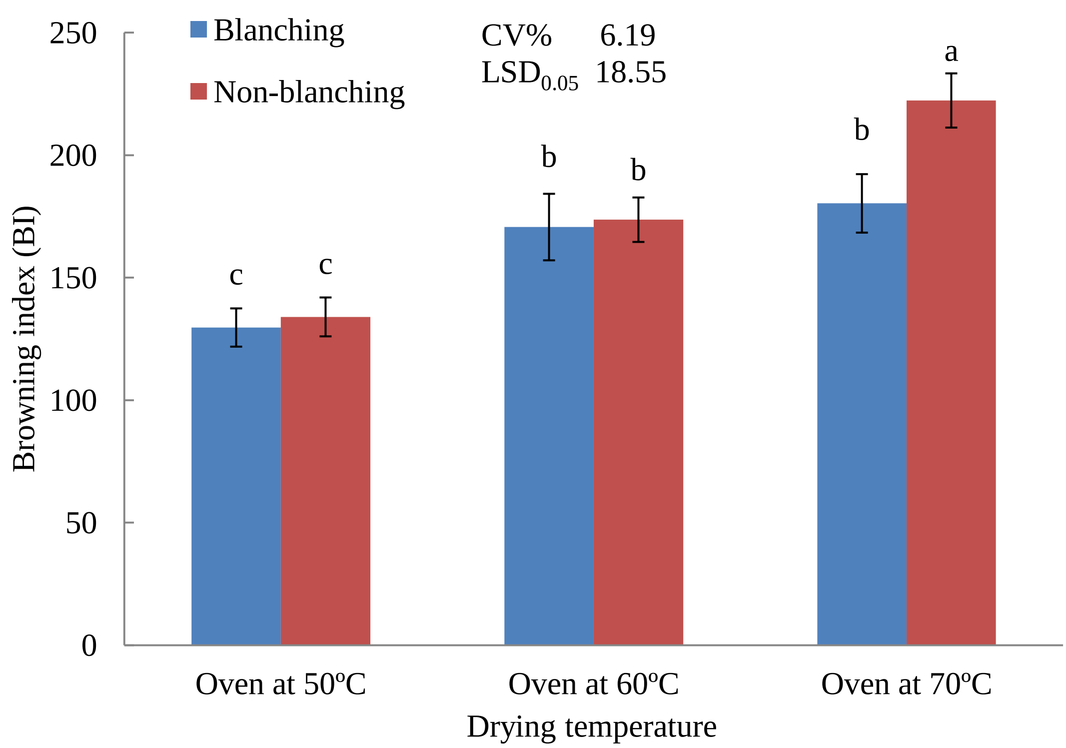


Figure 4.14 Effect of different drying temperatures and pretreatment on the browning index of dried chilli

4.2.5 Effect of different drying temperatures on ascorbic acid content

Data presented in Figure 4.14 reveals the ascorbic acid content of chilli dried using hot air oven drying method by different drying temperatures at 50ºC, 60ºC and 70ºC with blanching and non-blanching treatment. The ascorbic acid content of fresh chilli was 210 mg/100g. The drying temperature at 70ºC showed significantly lower in ascorbic content as compared to drying at 50ºC for blanched and non-blanched samples.

Attainment of optimum drying temperature at 50ºC resulted in the highest ascorbic acid content. Similarly, blanching must have resulted in more retention of the ascorbic acid content from dried chilli during drying. The lowest ascorbic acid content was found in chilli dried at 70ºC. This finding was in line with Ajaykumar et al., (2012) who also reported degradation of ascorbic acid by higher drying temperature. There was no interaction between the drying temperature and pretreatment in the retaining of ascorbic acid content in this study.

According to the quality parameter values mentioned above, the optimum drying temperature was 50ºC for drying of red chilli. This optimum temperature of 50ºC can prevent dark brown color formation and color change and can retain the ascorbic acid content compared to 60ºC and 70ºC. Therefore, the lower the drying air temperature, the better the quality of chilli can be achieved.

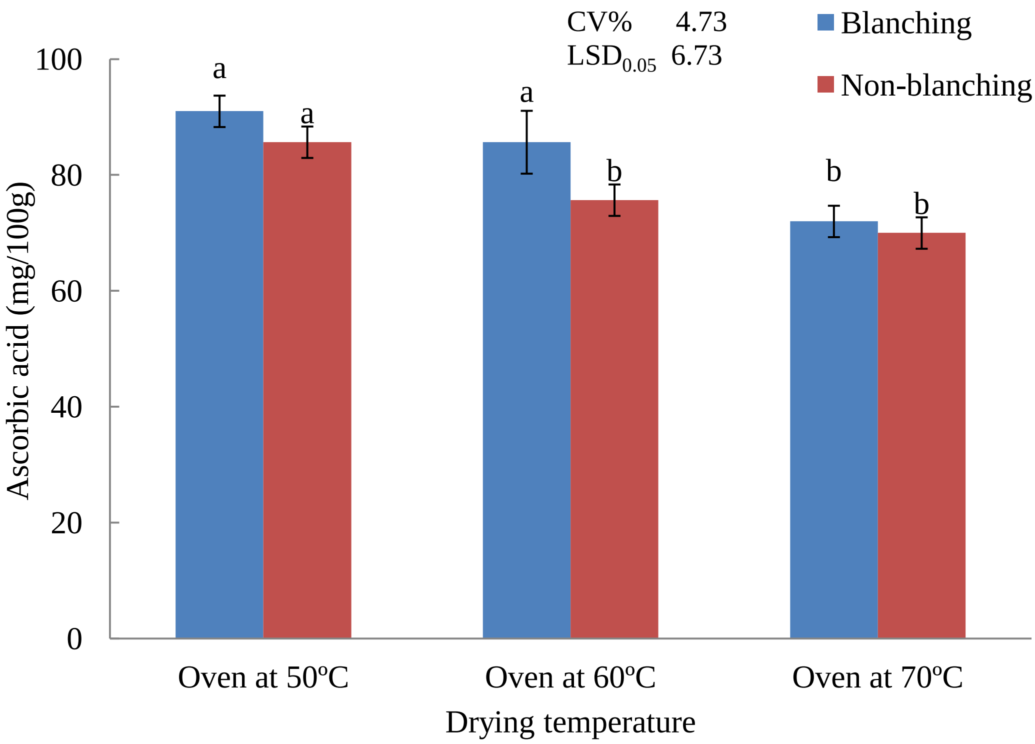


Figure 4.15 Effect of different drying temperatures and pretreatment on the ascorbic acid content of dried chilli

Table 4.6 Effect of different oven drying temperatures and pretreatment on moisture content, water activity, color difference, browning index and ascorbic acid content of dried chilli

Item	Moisture content (%)	Water activity	Color difference	Browning index	Ascorbic acid (mg/100g)
Drying temperature					
Oven at 50ºC	7.15 a	0.36 a	18.67 c	131.83 c	88.33 a
Oven at 60ºC	6.75 b	0.33 b	24.67 b	172.17 b	80.67 b
Oven at 70ºC	5.95 c	0.32 c	27.67 a	201.33 a	71 c
$LSD_{0.05}$	**0.39**	**0.01**	**1.67**	**13.12**	**4.76**
Pretreatment					
Blanching	6.50 a	0.34 a	23.22 a	160.22 b	82.89 a
Non-blanching	6.73 a	0.33 b	24.11 a	176.67 a	77.11 b
$LSD_{0.05}$	**0.32**	**0.008**	**1.37**	**10.71**	**3.89**
Pr > F					
Drying temperature	**	**	**	**	**
Pretreatment	ns	*	ns	**	**
Drying temperature x Pretreatment	ns	ns	ns	*	ns
CV (%)	4.71	2.43	5.63	6.19	4.73

Means in the same column by the same letters are not significant different at $P \leq 0.05$

ns = non significant * = significant at 5% level ** = highly significant at 1% level

4.3 Effect of Different Drying Methods on Quality of Dried Chilli

The quality parameters of dried chilli were observed in moisture content, water activity, colour difference, browning index, ascorbic acid content and aflatoxin content. The mean value of quality parameters as affected by different drying methods and pretreatment were shown in Table 4.7.

4.3.1 Effect of different drying methods on moisture content

Data presented in Figure 4.15 reveals the moisture content of chilli dried using two drying methods with blanching and non-blanching treatments. Solar tunnel dried with blanched chilli showed significantly low moisture content (6.2%) compared to open sun drying method (6.7%) and (7.3%) for blanched and non-blanched samples. Blanching treatment also exhibited considerably low moisture content compared to non-blanched samples.

Solar tunnel drying resulted in high moisture loss. This was due to air temperature in the solar tunnel which was observed to be much higher than the ambient air temperature (open sun drying). Similar finding has been reported by Hossain & Bala (2007) on the average air temperature rise (21.62ºC) at the outlet of the collector over ambient air temperature during solar drying of chilli. Similarly, blanching must have resulted in more cellular degeneration leading to more moisture loss from the produce during drying. There was no interaction effect on moisture content between different drying methods and pretreatment in this study.

4.3.2 Effect of different drying methods on water activity

Data presented in Figure 4.16 reveals the water activity of chilli dried using two drying methods with blanching and non-blanching treatments. The initial water activity of fresh chilli was 0.9936. Solar tunnel dried with non-blanched chilli showed among the treatments. Blanching treatment also exhibited significantly high water activity compared to non-blanched samples.

Solar tunnel drying resulted in low water activity. The value of water activity was lower in non-blanched samples as compared to blanched samples. Similar findings have been reported by Toure (1985) who also observed that unblanched samples had a lower water activity than blanched samples of dehydrated okra. There was a highly significant interaction between drying methods and pretreatment in water activity in this study.

4.3.3 Effect of different drying methods on color difference (ΔE)

Data presented in Figure 4.17 reveals the color difference of chilli dried using two drying methods namely open sun drying and solar tunnel drying with blanching and non-blanching treatments. Solar tunnel dried chilli showed significantly low in color difference compared to open sun dried with non-blanched chilli.

Solar tunnel drying resulted in low color difference. Similar findings had been reported by Hossain and Bala (2007) described significantly higher mean color difference values in conventionally sun dried red chilli than those obtained from solar tunnel dried chilli.. However, the data revealed no significant difference on the interaction effect between drying methods and blanching.

4.3.4 Effect of different drying methods on browning index

Data presented in Figure 4.18 reveals the browning index of chilli dried using two drying methods of open sun drying and solar tunnel drying with blanching and non-blanching treatments. Solar tunnel dried with blanched chilli showed significantly low in browning index as compared to open sun drying method.

Solar tunnel drying resulted in low browning index while the lowest value of browning index was observed in the blanched chilli dried with solar tunnel dryer. Open sun dried samples were high in browning index as compared to solar tunnel dried samples. Manjula & Ramachandra (2014) also reported that the solar tunnel drying method significantly improved the lightness and redness of dried chilli compared to the open yard sun drying method. However, there was no interaction between drying methods and pretreatment on browning index.

4.3.5 Effect of different drying methods on ascorbic acid content

Data presented in Figure 4.19 reveals the ascorbic acid content of chilli dried using two drying methods namely open sun drying and solar tunnel drying with blanching and non-blanching treatments. Solar tunnel dried chilli showed significantly high ascorbic acid content (121 mg/100g) and (110 mg/100g) compared to open sun drying method (91 mg/100g) and (77 mg/100g) for blanched and non-blanched samples respectively (appendix 4). Blanching treatment also exhibited significantly high ascorbic acid content compared to non-blanched samples. Blanching practice must have excluded the oxygen from the cells that perhaps resulted in checking the oxidative degradation of ascorbic acid.

Solar tunnel drying resulted in high ascorbic acid. Manjula & Ramachandra (2014) also reported that the sample dried under solar tunnel drying was found to have better retention of ascorbic acid content as compared with open yard sun drying. Similarly, blanching must have resulted in more retention ascorbic acid content from the produce during drying. There was no interaction between the drying methods and pretreatment in the retaining of ascorbic acid content in this study.

4.3.6 Total aflatoxin content (ppb) in all dried chilli

Data presented in Table 4.8 reveals the total aflatoxin content in all dried chilli. There was no aflatoxin content in all dried chilli sample except solar drying with blanched sample. The total aflatoxin content of solar tunnel drying with blanched sample was 0.06 (ppb) which was much below the maximum limit prescribed by CODEX. EU limited the maximum level of total aflatoxin content was 10ppb refer to (Commission Regulation (EC, 2006). Therefore, this contamination amount can be neglected. These findings were similar to Manjula & Ramachandra (2014) who also observed that the solar tunnel dried samples were found aflatoxin content with much below the prescribed maximum limit of CODEX.

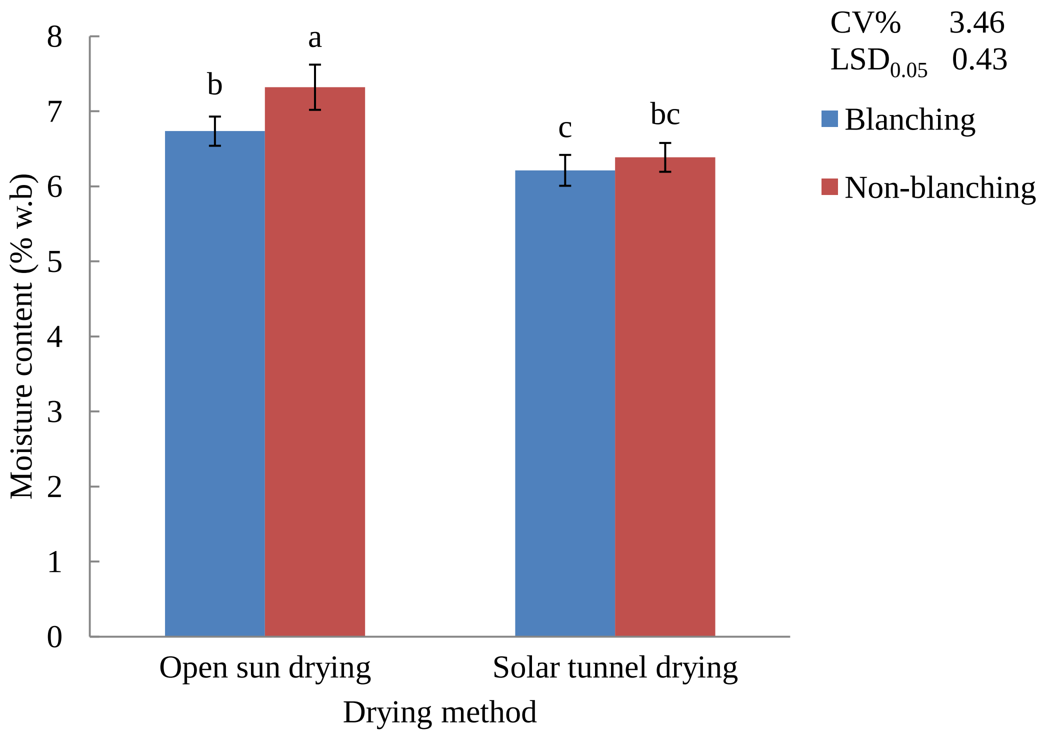


Figure 4.16 Effect of different drying methods and pretreatment on the moisture content of dried chilli

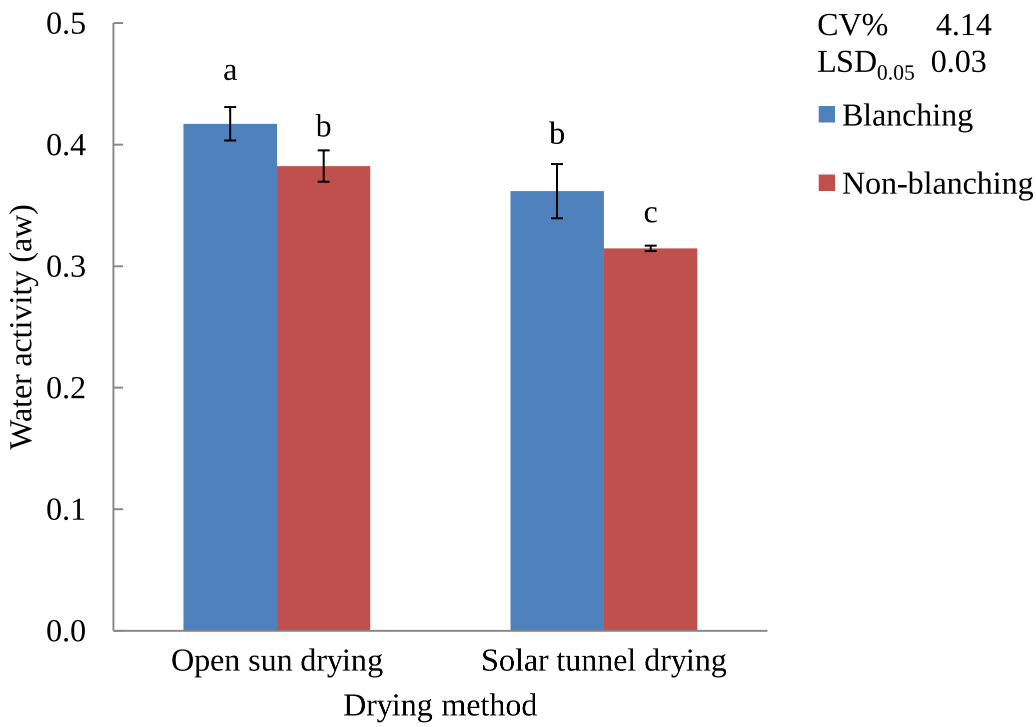


Figure 4.17 Effect of different drying methods and pretreatment on the water activity of dried chilli

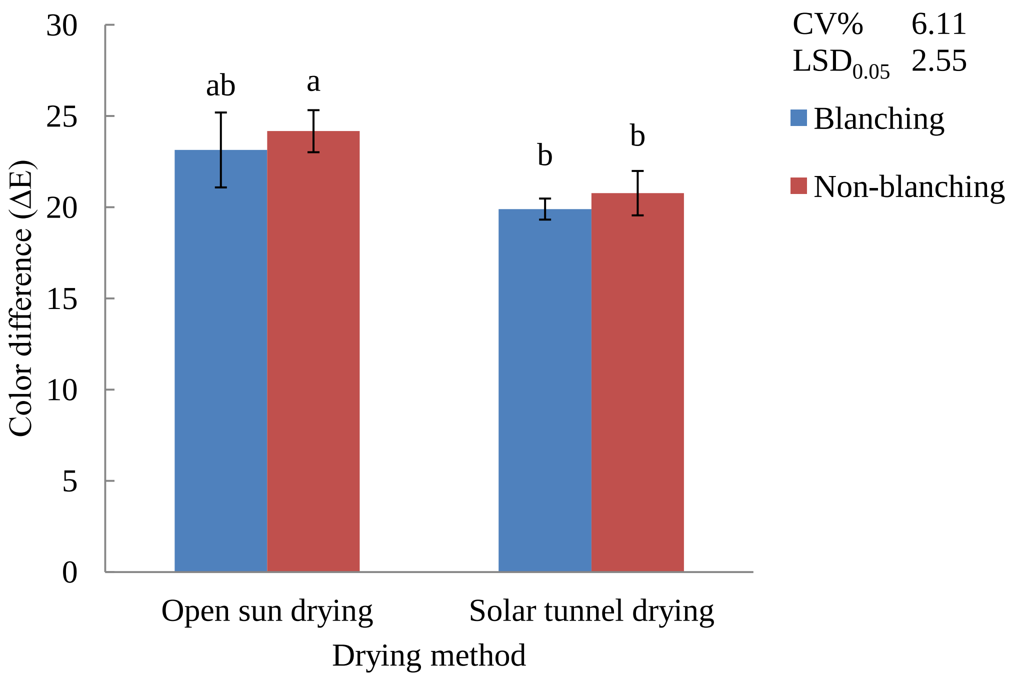


Figure 4.18 Effect of different drying methods and pretreatment on the color difference of dried chilli

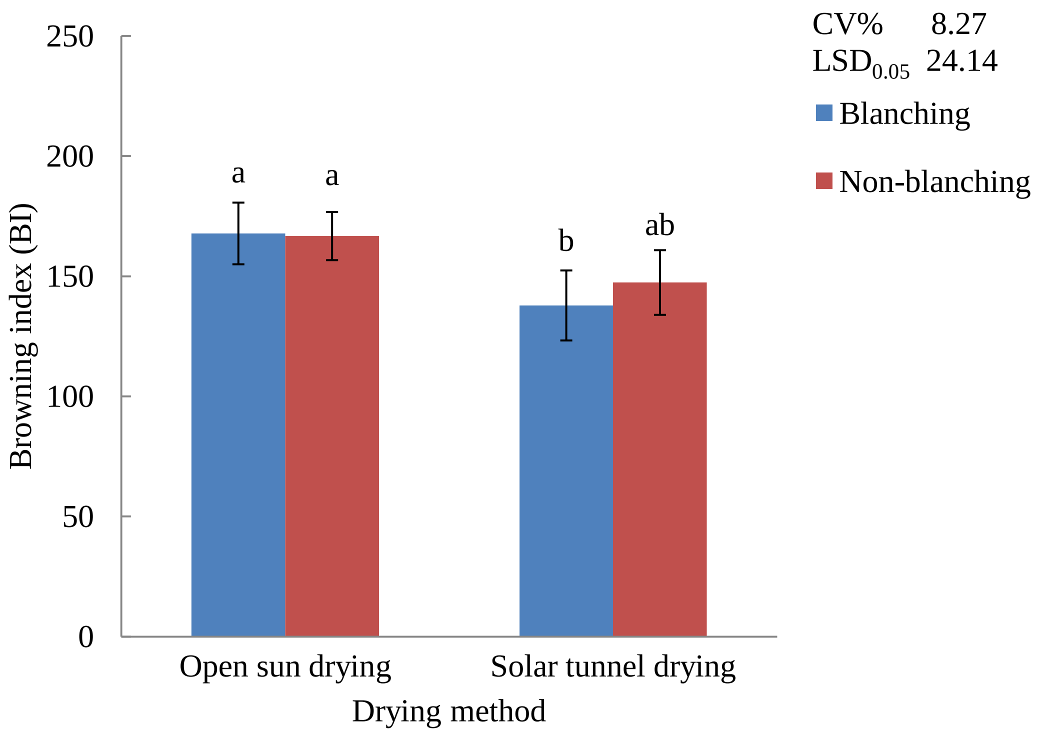


Figure 4.19 Effect of different drying methods and pretreatment on the browning index of dried chilli

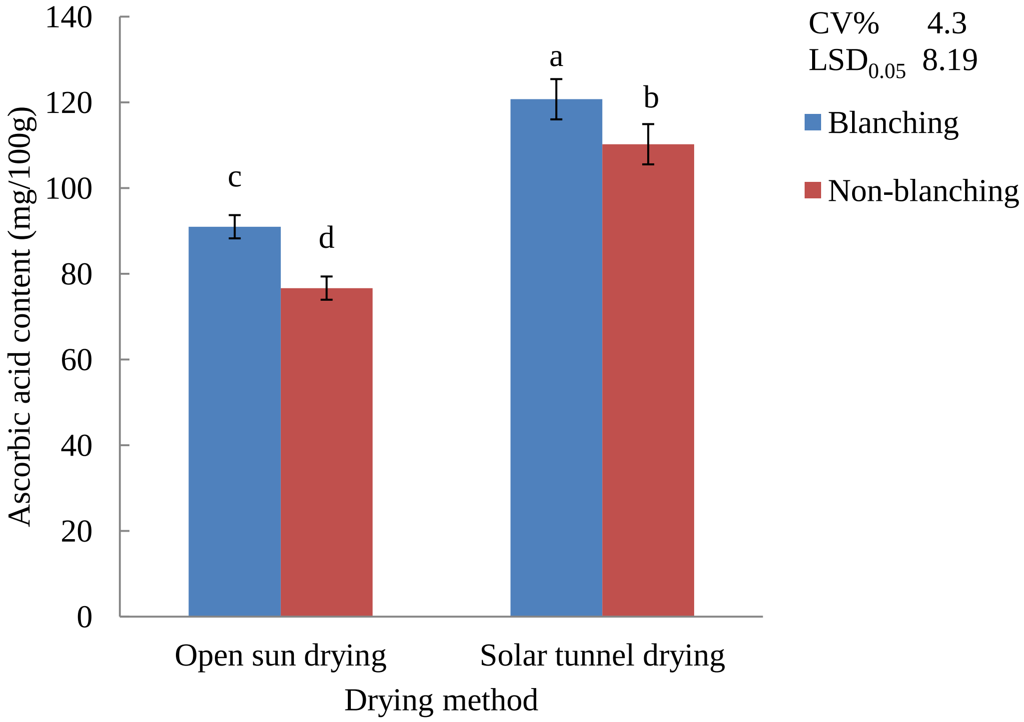


Figure 4.20 Effect of different drying methods and pretreatment on the ascorbic acid content of dried chilli

Table 4.7 Effect of different drying methods and pretreatment on moisture content, water activity, color difference, browning index and ascorbic acid content

Item	Moisture content (%)	Water activity	Color difference	Browning index	Ascorbic acid (mg/100g)
Drying method					
Open sun drying	7.00 a	0.40 a	23.50 a	167.17 a	86.67 b
Solar tunnel drying	6.33 b	0.34 b	20.83 b	142.83 b	115.67 a
$LSD_{0.05}$	0.31	0.02	1.80	17.07	5.79
Pretreatment					
Blanching	6.45 b	0.37 a	21.50 a	153 a	106.00 a
Non-blanching	6.88 a	0.36 a	22.83 a	157 a	96.33 b
$LSD_{0.05}$	0.31	0.02	1.80	17.07	5.79
Pr > F					
Drying method	**	**	**	*	**
Pretreatment	*	ns	ns	ns	**
Drying method x Pretreatment	ns	**	ns	ns	ns
CV (%)	3.46	4.14	6.11	8.27	4.30

Means in the same column by the same letters are not significant different at $P \leq 0.05$

ns = non significant   * = significant at 5% level   ** = highly significant at 1% level

Table 4.8 Total aflatoxin content (ppb) in all dried chilli samples

No.	Treatments (Dried samples)	Total aflatoxin content (ppb)
1.	Hot air oven drying at 50ºC with blanching sample (50B)	0.00
2.	Hot air oven drying at 50ºC with non-blanching sample (50NB)	0.00
3.	Hot air oven drying at 60ºC with blanching sample (60B)	0.00
4.	Hot air oven drying at 60ºC with non-blanching sample (60NB)	0.00
5.	Hot air oven drying at 70ºC with blanching sample (70B)	0.00
6.	Hot air oven drying at 70ºC with non-blanching sample (70NB)	0.00
7.	Open sun drying with blanching sample (OB)	0.00
8.	Open sun drying with non-blanching sample (ONB)	0.00
9.	Solar tunnel drying with blanching sample (SB)	0.06
10.	Solar tunnel drying with non-blanching sample (SNB)	0.00

*ppb = parts per billion

CHAPTER V
CONCLUSION

The effects of drying methods with blanching and non-blanching on the quality of dried chilli were investigated. In this study, the red chilli were dried by hot air oven drying of different temperatures at (50ºC, 60ºC and 70ºC) with blanching and non-blanching. Among the oven temperatures, 50ºC was found the optimum temperature for drying of red chilli due to lesser in browning index, color difference and more retention in ascorbic acid content as compared to drying at 60ºC and 70ºC. The oven drying method at 50ºC took the longest drying time of 27 hours for blanched and 30 hours for non-blanched chilli and followed by the drying temperatures of 60ºC and 70ºC. The hot air oven drying method at 70ºC took the lowest time for drying. However, the quality of dried chilli treated at that temperature not only remarkably increased browning index and color difference but also decreased in ascorbic acid content. In terms of blanching, there were no significant differences in moisture content and color difference of dried chilli among the oven drying treatments. In oven drying of red chilli, blanching process considerably exhibited higher retention of ascorbic acid content with lesser value in browning index than non-blanched chilli. Therefore, pretreatment blanching process was more effective in oven drying of chilli by inactivating enzyme activity that prevented color degradation and vitamin C losses.

The second experiment was conducted to assess drying characteristic and quality of dried chilli using different drying methods of open sun drying and solar tunnel drying. In drying of chilli, the average temperature for open sun drying was around 45ºC and it took 25 hours while solar tunnel drying with indirect solar cabinet was around 60ºC and 19 hours with non-blanching. The dried red chilli by solar tunnel drying had considerably low in moisture content and water activity with less value of browning index and color difference as compared to open sun drying method. Moreover, solar tunnel drying method was significantly superior in retaining the ascorbic acid content than open sun drying of red chilli. Blanched chilli had significantly higher in ascorbic acid content with less moisture content than non-blanched chilli. There were no significant differences in browning index and color difference between blanching and non-blanching treatments. The aflatoxin content was found to be either nil or much below the permitted limits among the treatments.

Based on the results, solar tunnel drying method was found the most suitable method due to rapid drying, less moisture content, low water activity, less in browning index and color difference with high ascorbic acid content. Blanching should be done in drying of red chilli to retain ascorbic acid and less moisture content and to hasten the drying process. Further research for variation of capsaicin content on drying of red chilli needs to be conducted.

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APPENDICES

Appendix 1 Drying time (hours) in all drying methods of red chilli

No	Drying Methods	Drying Time (hours)
1.	Oven drying at 50ºC with blanching (50B)	27
2.	Oven drying at 50ºC with non-blanching (50NB)	30
3.	Oven drying at 60ºC with blanching (60B)	17
4.	Oven drying at 60ºC with non-blanching (60NB)	18
5.	Oven drying at 70ºC with blanching (70B)	11
6.	Oven drying at 70ºC with non-blanching (70NB)	11
7.	Open sun drying with blanching (OB)	23
8.	Open sun drying with non-blanching (ONB)	25
9.	Solar tunnel drying with blanching (SB)	19
10.	Solar tunnel drying with non-blanching (SNB)	19

Appendix 2 Daily record of temperature and relative humidity at ambient for April 2019

Date	Temperature (ºC)		Relative humidity %(RH)	
	Minimum	Maximum	Minimum	Maximum
10.4.2019	40.6	42.8	18	25
11.4.2019	39.9	45.3	14	26
12.4.2019	36.1	47.9	12	35
13.4.2019	39.8	51.6	15	41
14.4.2019	38.1	45.2	23	44

Appendix 3 Daily record of temperature and relative humidity at solar tunnel for April 2019

Date	Temperature (ºC)		Relative humidity %(RH)	
	Minimum	Maximum	Minimum	Maximum
10.4.2019	48.7	59.9	22	30
11.4.2019	48	56.58	15	27
12.4.2019	54.4	66.1	11	25
13.4.2019	52.3	67.8	11	23

Appendix 4 Effect of different oven drying temperatures and drying methods on quality of dried chilli

Treatments	Drying time(h)	Moisture content (%)	Water activity	Color difference (ΔE)	Browning index (BI)	Ascorbic acid content (mg/100g)
50B	27	7.03	0.36	19	134	91
50NB	30	7.33	0.35	18	130	86
60B	17	6.63	0.34	26	174	86
60NB	18	6.87	0.33	24	171	75
70B	11	5.87	0.32	28	222	72
70NB	11	6.03	0.31	28	180	70
OB	23	6.72	0.42	24	167	91
ONB	25	7.30	0.38	23	168	77
SB	19	6.20	0.36	21	147	121
SNB	19	6.47	0.31	20	138	110

50B = Oven drying at 50ºC with blanching

50NB = Oven drying at 50ºC with non-blanching

60B = Oven drying at 60ºC with blanching

60NB = Oven drying at 60ºC with non-blanching

70B = Oven drying at 70ºC with blanching

70NB = Oven drying at 70ºC with non-blanching

OB = Open sun drying with blanching

ONB = Open sun drying with non-blanching

SB = Solar tunnel drying with blanching

SNB = Solar tunnel drying with non-blanching

Appendix 5 Farm survey on the existing practices being followed by the farmers for drying of chilli

1.	Farmer's name	**U Nyein Chan Aung**	**U Aung Kyaw Soe**	**Daw Yi Hla**	**U Maung Win**	**U Moe Aung**
2.	Products (whole dried chilli/ chilli powder)	whole dried chilli	whole dried chilli	whole dried chilli	whole dried chilli	whole dried chilli
3.	Raw material type (fresh/dried chilli)	Fresh chilli	Fresh chilli	Fresh chilli	Fresh chilli	Fresh chilli
4.	Raw material procurement	Own fields	Own fields	Own fields	Own fields	Own fields
5.	Land ownership	1.38 acre	12 acre	2 acre	2.5 acre	
6.	Cultivar	004, 222, 692	004 (Jade)	222 (demon)	004 (Jade)	004 (Jade)
7.	Blanching before drying	No	No	No	No	No
8.	Others pretreatment	No	No	No	No	No
9.	Drying methods	Open sun drying	Open sun drying	Open sun drying	Open sun drying	Open sun drying
10.	Drying machinery and capacity	Not application	Not application	Not application	Not application	Not application
11.	Drying temperature and relative humidity	Not recorded	Not recorded	Not recorded	Not recorded	Not recorded
12.	Duration of drying	4-5 days	5 – 6 days	4-5 days	2-3 days	4-5 days
13.	Moisture content of dried chilli	Not measured	Not measured	Not measured	Not measured	Not measured
14.	Packaging material	Gunny sack	Gunny sack	Gunny sack	Gunny sack	Gunny sack
15.	Storage condition	with tarpaulin in room	heap up in house	heap up in house	heap up in house	heap up on tarpaulin
16.	Storage life (depend on market	2-3 month	6-7 month	6-7 month	6-7 month	6-7 month
17.	Sale price of dried chilli (kyats/viss)	4000-6000	4000-7000	6000-7000	4000-7000	4000-7000
18.	Sale price of fresh chilli (Kyats/viss)	2000-3000	2000-3000	2000-3000	2000-3000	2000-3000

Source: Farm survey was conducted at Kan Swal Village, Yamethin Township for current cultural practice and drying practice of chilli (May, 2019).

Appendix 6 Dried chilli and powder after dying with blanching and non-blanching by different drying methods

Appendix 7 Nutrient content of fresh red chilli

Nutrient content of fresh red chili (*Capsicum annuum*) per 100 g.			
Principle	**Nutrient value**	**Principle**	**Nutrient value**
Energy	40 Kcal	**Minerals**	
Carbohydrates	8.81 g	Calcium	14 mg
Protein	1.87 g	Copper	0.129 mg
Dietary Fiber	1.5 g	Iron	1.03 mg
Vitamins		Magnesium	23 mg
Folates	23 µg	Manganese	0.187 mg
Niacin	1.244 mg	Phosphorus	43 mg
Thiamin	0.72 mg	Selenium	0.5 µg
Vitamin A	952 IU	Zinc	0.26 mg
Vitamin C	143.7 mg	**Phyto-nutrients**	
Vitamin E	0.69 mg	Carotene-ß	534 µg
Vitamin K	14 µg	Carotene-α	36 µg
Electrolytes		Cryptoxanthin-ß	40 µg
Sodium	9 mg	Lutein-zeaxanthin	709 µg
Potassium	322 mg		

(Source: USDA National Nutrient data base)