CHAPTER X

CONCLUSION AND FURTHER RESEARCH

In this chapter, the briefly summarized the findings of this dissertation and the various parts of it are firstly presented. Drying procedure for each dried product type is concluded and presented in the second section. Moreover, the implication for further research is addressed as well.

10.1 Conclusion

In the introduction chapter 1, it starts with the research problem motivated by a real world situation. Chapter 2 shows the literature that relevant to the statement of the problem. Next in chapter 3, the methodology for this dissertation is described. The chapter of the methodology describes about the steps for determining the optimal drying time for each drying phase, for reducing the dried product quality variation in the raw materials and the drying process, and for validating the mathematical models with the real drying process. The experimental results of the determination of the optimal drying time are presented in chapter 4. After finding the optimal drying time, the results of the quality variation management in the raw material are shown in chapter 5. After reducing the dried product quality variation from the raw material, the reduction of the dried product quality variation from the drying process are studied in chapter 6, 7, and 8 as following three drying phases. Finally, the results of the validation of the quality variation management are presented in chapter 9.

In total, the objective of this dissertation is to develop the mathematical models for managing the quality variation for the drying process in Thai agro-industry. Theses mathematical models can help to reduce and minimize the quality variation of the dried products in order to increase the quality of the dried products. Then, this dissertation is built around two main contributions by:

(1) Illustrating the statistical relationship between the dried product quality variation and the source of the quality variation (the raw material and the process); and

(2) Proposing how to control and adjust the drying process for managers or engineers in order to control the quality of the dried products.

In the following sections, the outcomes of this dissertation will be summarized.

10.1.1 Dissertation Problem

Production of the dried product in Thai agro-industry has expanded vigorously for a long time. It can help to prolong the shelf life of the agricultural products. Moreover, transportation and storage costs are lower than other fresh products. Express deliveries and refrigeration storages which are high costs are not required for the dried products. However, quality of the dried product is a serious problem for the drying process industry. It is very difficult to control the quality of the raw materials consistently since they depend on several uncontrolled natural factors such as climate, weather, and seasonality.

There are several researches attempting to improve the quality of the dried product. Most of researches were still focused on developing the dryers with the new technologies. While the studies of the drying process control are hardly found. For the meantime, the major cost of the dryers is not in the initial investment (design and assembly) but in the daily operation. The drying process control is very important to obtain the quality of the dried product and to save the drying energy. Therefore, this dissertation focuses only the drying process control with two considerations as the raw material and the drying process.

The topic of this dissertation is to reduce the dried product quality variation. To measure the dried product quality variation, Mean Squared Deviation or *MSD* is used to be a dried product quality variation measure. There are several drying parameters affecting the dried product quality variation such as velocity and humidity of the drying media. However, only two major parameters are studied in this dissertation. The first parameter is the drying time and the second parameter is the drying temperature level.

In this dissertation, four types of dried product in Thai agro-industry are selected to be case studies. They are paddy rice, cassava chip, tobacco, and longan. All of them are the most important commercial dried products of Thailand.

10.1.2 Determination of Drying Time

Drying time is the first drying parameters which are studied in this dissertation. The aim of this section is to determine the drying time for each drying phase within each type of the dried product. The experimental results are shown as in Table 10.1.

Table 10.1 Summary of drying time for each drying phase

Product	Optimal Drying Time for Each Drying Phase		
	Heating Phase	**Drying with a Constant rate Phase**	**Drying with Falling Rate Phase**
Paddy rice	30 seconds	5 minutes	12 hours
Cassava chip	5 minutes	20 minutes	15 minutes
Tobacco	3 minutes	10 minutes	5 minutes
Longan	15 hours	15 hours	10 hours

10.1.3 Quality Variation Management in Raw Material

Raw material is the first source of the dried product quality variation. Its variety is a major cause that the agro-industry cannot control the quality of the dried product. Therefore, the variety of the raw material has to be reduced in order to minimize the dried product quality variation from this variety. Fuzzy c-means clustering is used to organize the raw materials into their clusters. From the results, three clusters is the optimal number of clustering the raw material. Three clusters are labeled as low, medium, and high moisture content. Thus, the raw materials have to classify into their clusters with the criteria in Table 10.2 before drying.

Table 10.2 Summary range of the moisture content for clustering the raw material

Product	Cluster	Range of Moisture Content (% w.b.)
Paddy rice	Low	22.1 – 25.3
	Medium	25.4 – 27.0
	High	27.1 – 29.0
Cassava chip	Low	40.2 – 55.5
	Medium	55.6 – 62.4
	High	62.5 – 73.4
Tobacco	Low	15.0 – 17.6
	Medium	17.7 – 19.4
	High	19.5 – 22.4
Longan	Low	84.6 – 89.5
	Medium	89.6 – 93.0
	High	93.1 – 97.0

10.1.4 Quality Variation Management in Drying Process within Heating Phase

Heating phase is the first phase of the drying process, but it is neglected to study. Therefore, it is scoped in this dissertation. The aim of heating phase is to heat the raw material without reducing the moisture content of the heated raw material. Therefore, the optimal heating temperature level for each dried product type is required. Moreover, the mathematical models for heating the raw materials are constructed to investigate the behavior of the moisture content during the heating period time. The results of finding the optimal heating temperature level are shown as in Table 10.3.

Table 10.3 Summary results of drying process within heating phase

Product	Heating Time	Initial Moisture Content	Optimal Temperature Level (°C)	Mathematical model
Paddy rice	30 seconds	Low	55	$M(t)_1 = 23.9$
		Medium	60	$M(t)_1 = 26.6$
		High	63	$M(t)_1 = 27.8$
Cassava chip	5 minutes	Low	90	$M(t)_1 = 52.4$
		Medium	100	$M(t)_1 = 60.1$
		High	110	$M(t)_1 = 67.6$
Tobacco	3 minutes	Low	55	$M(t)_1 = 17.1$
		Medium	60	$M(t)_1 = 18.3$
		High	65	$M(t)_1 = 20.0$
Longan	15 hours	Low	70	$M(t)_1 = 87.4$
		Medium	75	$M(t)_1 = 91.1$
		High	77	$M(t)_1 = 94.3$

10.1.5 Quality Variation Management in Drying Process within a Constant Drying Rate Phase

After the raw materials are heated within the heating phase, they are transferred to the second phase of the drying process. The aim of the second phase is to dry the heated raw materials to the target of the moisture content with a constant drying rate. Therefore, the optimal drying temperature level for each dried product type is required. Moreover, the mathematical models for drying the heated raw materials are constructed to investigate the behavior of the moisture content during the period of a constant drying rate phase. The results of finding the optimal drying temperature level are shown as in Table 10.4.

Table 10.4 Summary results of drying process within a constant drying rate phase

Product	Drying Time	Moisture Content	Optimal Temperature Level (°C)	Mathematical model
Paddy rice	5 minutes	Low	110	$M(t)_2 = 23.4 - 0.919t$
		Medium	120	$M(t)_2 = 26.1 - 1.42t$
		High	125	$M(t)_2 = 27.7 - 1.75t$
Cassava chip	20 minutes	Low	90	$M(t)_2 = 52.3 - 1.12t$
		Medium	100	$M(t)_2 = 60.2 - 1.51t$
		High	110	$M(t)_2 = 67.6 - 1.88t$
Tobacco	10 minutes	Low	60	$M(t)_2 = 17.0 - 0.302t$
		Medium	65	$M(t)_2 = 18.3 - 0.43t$
		High	70	$M(t)_2 = 20.0 - 0.604t$
Longan	15 hours	Low	70	$M(t)_2 = 87.4 - 0.962t$
		Medium	85	$M(t)_2 = 91.1 - 1.2t$
		High	88	$M(t)_2 = 94.1 - 1.39t$

10.1.6 Quality Variation Management in Drying Process within Falling Drying Rate Phase

After drying in the second phase, the raw materials are dried again within the last phase. In the last phase of the drying process, the raw materials are dried with falling drying rate. It means that drying rate is not a constant. The aim of the third phase is to dry the raw materials from the second phase to the target of the moisture content with falling drying rate. Therefore, the optimal drying temperature level for each dried product type is required. Moreover, the mathematical models for drying the raw materials are constructed to investigate the behavior of the moisture content during the period of falling drying rate phase. From the results, the raw materials cannot be reduced the moisture content to their targets within only the drying with falling rate phase. Therefore, another drying period is developed to reduce the moisture content of the raw materials to their targets by this dissertation. This developed drying period is called adjustment drying temperature period. The level of the drying temperature from the falling drying rate period is adjusted in the adjustment drying temperature period. The results of finding the optimal drying temperature level are shown as in Table 10.5 and 10.6.

Table 10.5 Summary results of drying process within falling drying rate phase

Product	Drying Time	Optimal Temperature Level (°C)	Mathematical model
Paddy rice	6 hours	60	$M(t)_3 = 14.2 + 4.9e^{(-t/3.8)}$
Cassava chip	12 minutes	100	$M(t)_3 = 14.2 + 15.8e^{(-t/3.93)}$
Tobacco	5 minutes	50	$M(t)_3 = 12.5 + 1.5e^{(-t/1.35)}$
Longan	6 hours	85	$M(t)_3 = 19 + 54e^{(-0.45t)}$

Table 10.6 Summary results of drying process within adjustment drying temperature period

Product	Drying Time	Optimal Temperature Level (°C)	Mathematical model
Paddy rice	6 hours	65	$M(t)_4 = 15.0 - 0.189t$
Cassava chip	3 minutes	120	$M(t)_4 = 14.3 - 0.12t$
Longan	4 hours	88	$M(t)_4 = 22.1 - 1.08t$

10.1.7 Validation

After all drying temperature levels and mathematical models are established, they are used in the real drying process in order to ensure that they can be used to reduce and minimize the dried product quality variation. The results of the validation can be illustrated in Table 10.7. Moreover, the results of the reduction of the dried product quality variation can be summarized in Table 10.8.

Table 10.7 Summary of the results of the validation

Product	Range of moisture content	Output moisture content (%w.b.)		Average of difference (%)
		Mathematical models	Real process	
Paddy rice	Low	14.1	13.8	0.83
	Medium	14.1	14.0	1.30
	High	14.1	13.8	1.83
Cassava chip	Low	13.9	13.5	1.93
	Medium	13.9	13.5	3.17
	High	13.9	14.1	1.97
Tobacco	Low	12.5	12.2	2.37
	Medium	12.5	12.2	1.74
	High	12.5	12.3	1.91
Longan	Low	18.0	17.8	1.71
	Medium	18.0	17.9	1.75
	High	18.0	18.0	1.82

Table 10.8 Summary of the reduction of the dried product quality variation

Product	*MSD* (% w.b.)^2	
	Conventional Method	**This Dissertation**
Paddy rice	3.655	0.030
Cassava chip	7.691	0.170
Tobacco	2.902	0.070
Longan	10.758	0.020

10.2 Drying Procedure

After all results are concluded in the section 10.1, they are summarized and proposed as four procedures for drying the dried products which are the case studies of this dissertation.

10.2.1 Paddy Rice

Paddy rice is organized into three clusters. The first cluster is paddy rice within low moisture content (22.1-25.3% w.b.). The second cluster is paddy rice within medium moisture content (25.4-27.0% w.b.). The third cluster is paddy rice within high moisture content (27.1-29.0% w.b.). Then, paddy rice after clustering is heated and dried with drying procedure shown as Figure 10.1.

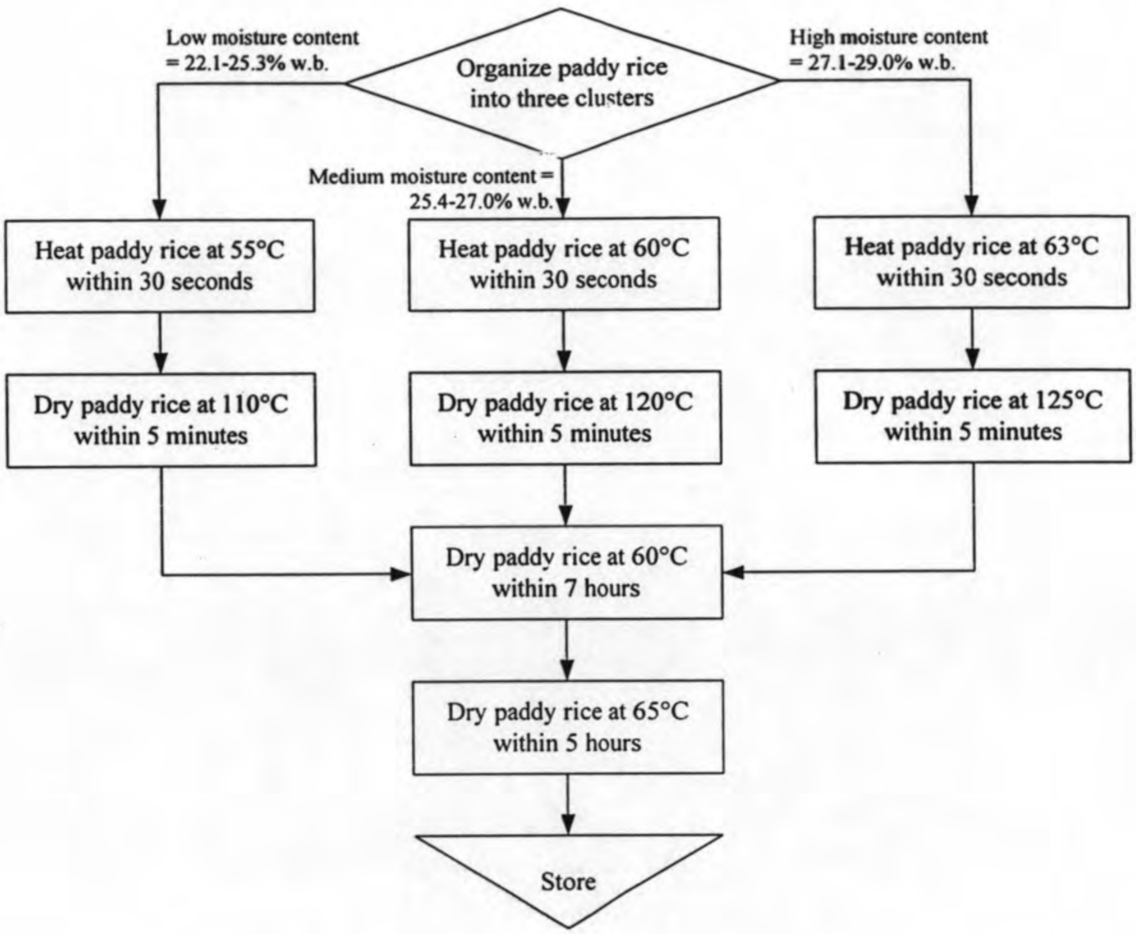

Figure 10.1 Drying procedure for paddy rice

10.2.2 Cassava Chip

Cassava chip is organized into three clusters. The first cluster is paddy rice within low moisture content (40.2-55.5% w.b.). The second cluster is paddy rice within medium moisture content (55.6-62.4% w.b.). The third cluster is paddy rice within high moisture content (62.5-73.4% w.b.). Then, cassava chip after clustering is heated and dried with drying procedure shown as Figure 10.2.

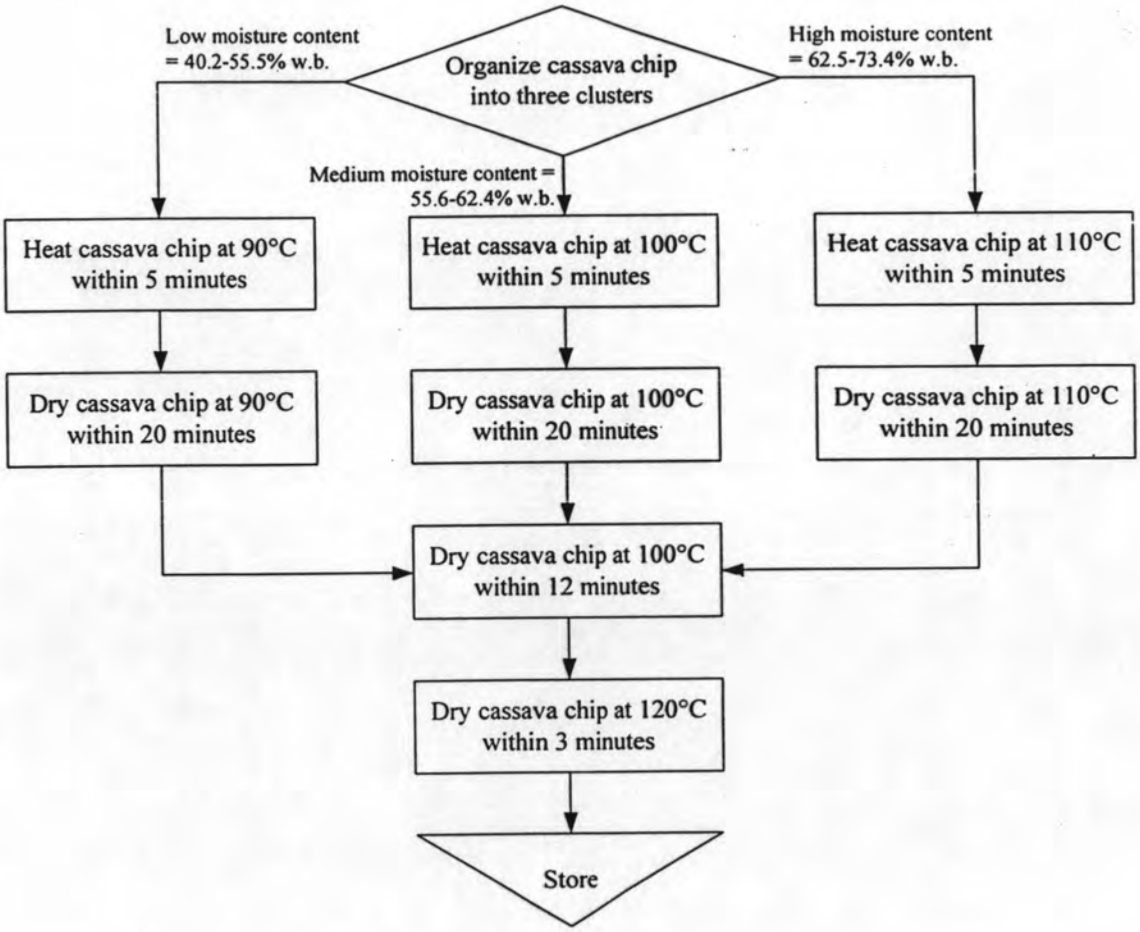

Figure 10.2 Drying procedure for cassava chip

10.2.3 Tobacco

Tobacco is organized into three clusters. The first cluster is paddy rice within low moisture content (15.0-17.6% w.b.). The second cluster is paddy rice within medium moisture content (17.6-19.4% w.b.). The third cluster is paddy rice within high moisture content (19.5-22.4% w.b.). Then, tobacco after clustering is heated and dried with drying procedure shown as Figure 10.3.

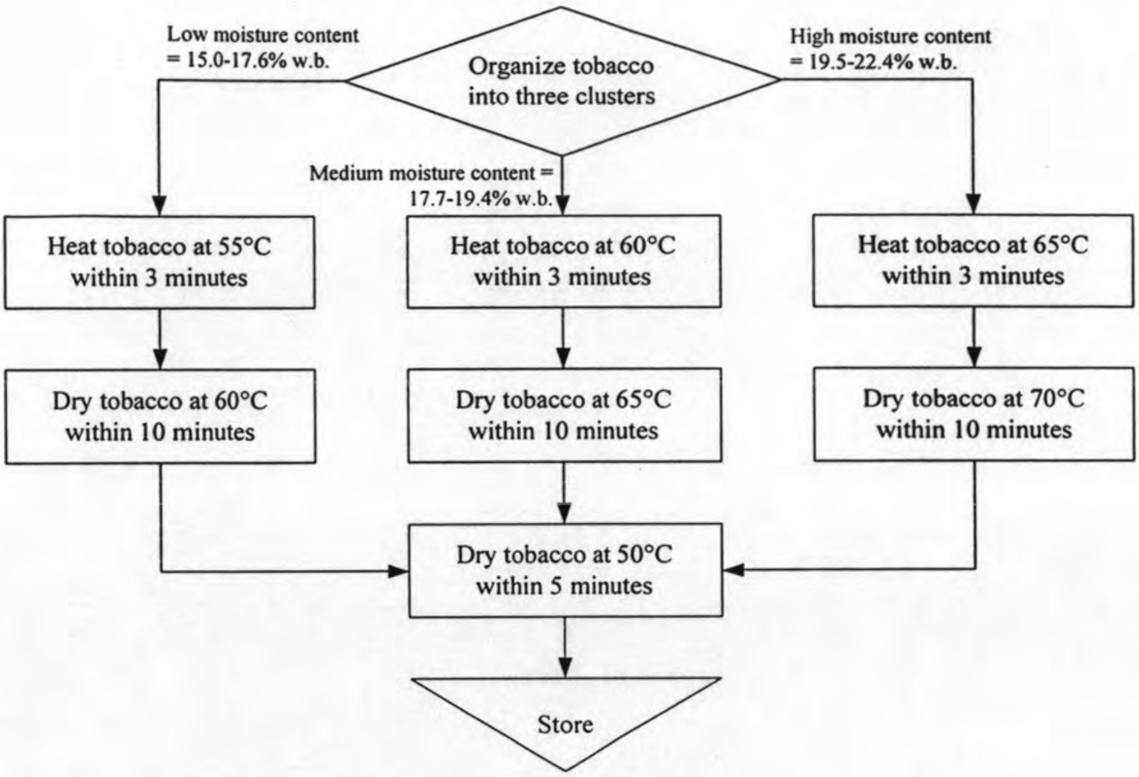

Figure 10.3 Drying procedure for tobacco

10.2.4 Longan

Longan is organized into three clusters. The first cluster is paddy rice within low moisture content (84.6-89.5% w.b.). The second cluster is paddy rice within medium moisture content (89.6-93.0% w.b.). The third cluster is paddy rice within high moisture content (93.1-97.0% w.b.). Then, longan after clustering is heated and dried with drying procedure shown as Figure 10.4.

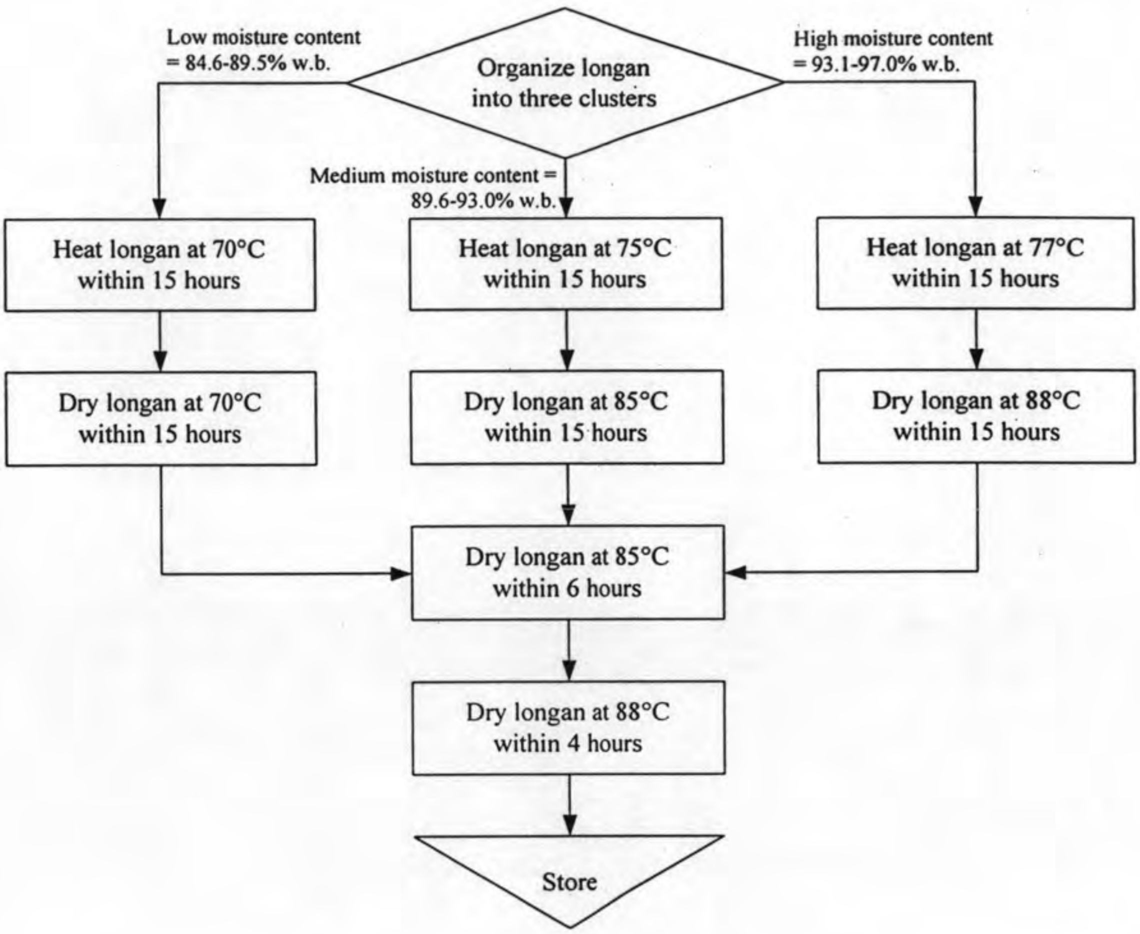

Figure 10.4 Drying procedure for longan

10.3 Further Research

This dissertation has provided new insights into the drying process for Thai agro-industry. Optimal drying time and drying temperature level for each drying phase is found to minimize the dried product quality variation in term of Mean Squared Deviation or *MSD*. Moreover, the mathematical models for drying the agricultural products are constructed. The outcomes provide interesting perspectives for further research with the drying process for Thai agro-industry.

First of all, the objective function of this dissertation is only the minimization of *MSD*, a measure of the dried product quality variation. In commercial system, drying production yield is another objective function which is concerned and determined by the agro-industry. To improve the drying process, the objective function as the maximization of the yield product can be added to the further study.

Secondly, only two drying parameters are studied in this dissertation, while there are more drying parameters affecting the quality of the dried product such as velocity of the drying media, seasonality of the raw material, and environment factors. Therefore, the further research can add more the drying parameters in order to come closer the real drying process.

Finally, the last suggestion of the further research is the extension to the storage system. The moisture content of the dried product is very sensitive to the surrounding and environment factors. Therefore, to prevent the changing of the moisture content after drying, the storage system is required to maintain the dried products before delivering to the customers and the users.