CHAPTER III

METHODOLOGY

In this chapter, methodology of this dissertation is presented as the direction to achieve the dissertation objective. The methodology is divided into seven steps. In the first step, defining the problem is explained in Section 3.1. After the problem of this dissertation is defined, the drying time for each drying phase is determined in the second step described in Section 3.2. In the third step, the method for reducing the dried quality variation from the raw material is presented in Section 3.3. After reducing the dried quality variation from the raw material, the method in the fourth steps as reducing the dried quality variation from heating phase is presented in Section 3.4. In the fifth step, the method for reducing the dried quality variation from drying with a Constant Drying Rate phase is explained in Section 3.5. In the sixth step, the method for reducing the dried quality variation from drying with Falling Drying Rate phase is explained in Section 3.6. Finally, to ensure that all of methodology can be used to be the direction of this dissertation, in the last step, validation method is presented in Section 3.7.

3.1 Defining the Problem

Drying process is the topic studied in this dissertation. From the Section 1.2, the statement of the problem of this dissertation is shown that the dried product quality variation is the major problem of the drying process in Thai agro-industry. However, the problem of the dried product quality variation can be classified into two cases described as below.

On the one hand, the first case of the dried quality variation problem is that the moisture content of the dried product is greater than the target. The higher moisture content than the target is a cause of the deterioration of the dried product by encouraging the excessive mould growth and the high respiration rate form the dried product (Tirawanichakul, et al., 2004).

On the other hand, the second case of the dried product quality variation is that the moisture content of the product is less than the target. Although the lower moisture content of the dried product can eliminate or stop the growth of mould, and the respiration rate, it cannot reduce the production costs. Water inside the product is evaporated over than the target. This is a cause that the dried product cannot achieve the yield target. Therefore, the manufacturers have to add more quantities of the dried product in order to meet the yield target.

From two cases of the dried product quality variation; hence, the aim of this dissertation is to reduce and minimize the dried product quality variation with both cases in order to improve the quality of the dried product. Moreover, four types of the dried product as paddy rice, cassava chip, tobacco, and longan are selected to case studies for this dissertation.

To measure the product quality variation, Taguchi proposed a statistical measure to evaluate the product quality variation in a term of *Mean Squared Deviation* or *MSD* (Taguchi, et al., 1989). It is used to measure the difference between the measured quality characteristic and its target. In this dissertation, *MSD* is used to measure the difference between the measured moisture content of the dried product and its target as shown in Equation (3.1).

$$MSD = \frac{1}{n}\sum_{i=1}^{n}(y_i - T)^2 \qquad (3.1)$$

where

y_i = the measured moisture content of the dried product

T = the target of the moisture content of the dried product

n = numbers of sample size

Therefore, the problem of this dissertation can be defined as Figure 3.1. It is related to quality variation management for drying process. This problem consists of three main units as raw materials, drying process, and dried product.

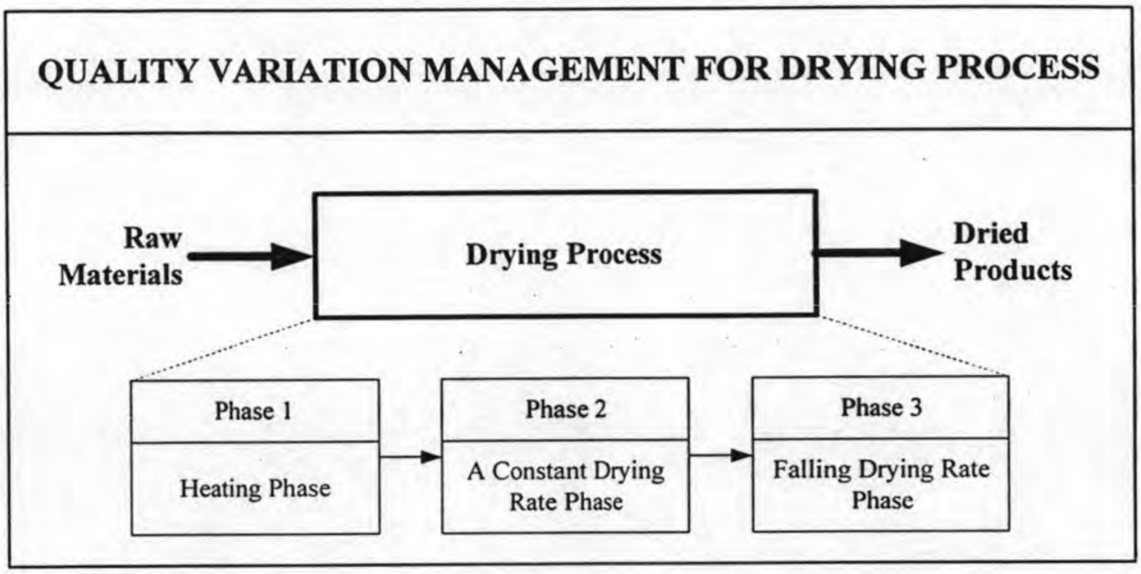

Figure 3.1 Quality variation management for drying process

In the first unit of the quality variation management for drying process, the raw material unit is firstly studied because it is the first source of the product quality variation of every type of product including the dried product. The quality variation is always from the variety of the quality of the raw material which cannot be controlled. It depends on several uncontrolled factors such as climate, seasonality, land fragmentation, and time. Thus, the variety of the quality of the raw material should be reduced or eliminated in order that the dried product quality variation is also reduced.

In the second unit, the drying process consists of three drying phases as the heating phase, the drying with a Constant Drying Rate phase, and the drying with Falling Drying Rate phase. Thus, the quality variation from the drying process should be also reduced and minimized in order to increase and maximize the quality of the dried product.

In the last unit, the dried products are the outputs from drying the agricultural products as the raw materials. Their qualities are already designed by the manufacturers or the customers. Thus, it is very necessary to meet this quality to increase the sale revenue.

3.2 Experimental Procedure for Determining Drying Time

Before conducting the quality variation management in drying process, the drying time for each drying phase is very important to determine. The drying time is used to any experiments for this dissertation. Therefore, the aim of this step is to determine the drying time with minimum *MSD* for each drying phase. Experimental procedure of this step can be illustrated in Figure 3.2.

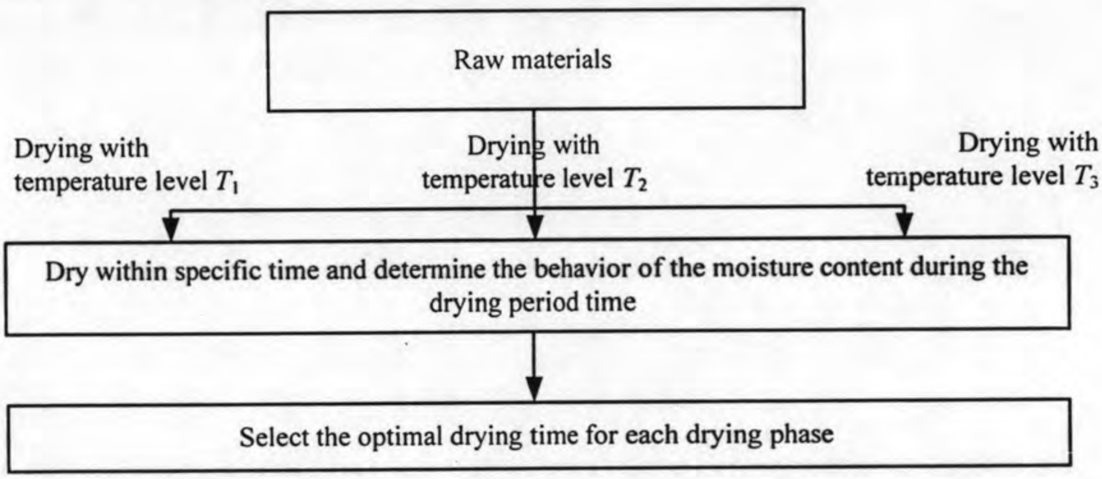

Figure 3.2 Experimental procedure for determining the drying time

3.2.1 Paddy Rice

Paddy rice is transferred to the drying process with three drying phases. Firstly, paddy rice is heated within heating phase. Secondly, heated paddy rice is dried with a constant drying rate phase. Finally, dried paddy rice from the second phase is dried again with falling drying rate phase.

(1) Heating Phase

In this phase, experiments are conducted to find the heating time for paddy rice. Heating temperature levels are varied at 55, 60, and 65°C. For each heating temperature level, heating times are specified at 40 seconds. Moreover, each experiment is conducted with five replicates. All experiments of heating paddy rice are summarized in Figure 3.3.

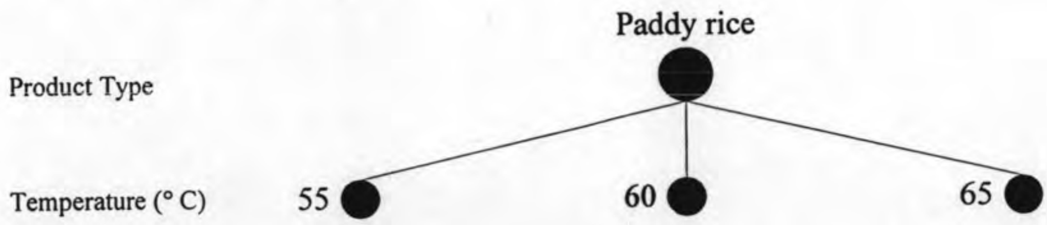

Figure 3.3 Heating time of paddy rice

(2) Drying with a Constant Drying Rate Phase

In this phase, experiments are conducted to find the drying time for paddy rice. The experiments are conducted by varying levels of drying temperature at 110, 120, and 130°C. For each drying temperature level, drying times are specified at 10 minutes. Moreover, each experiment is conducted with five replicates. All experiments of drying paddy rice are summarized in Figure 3.4.

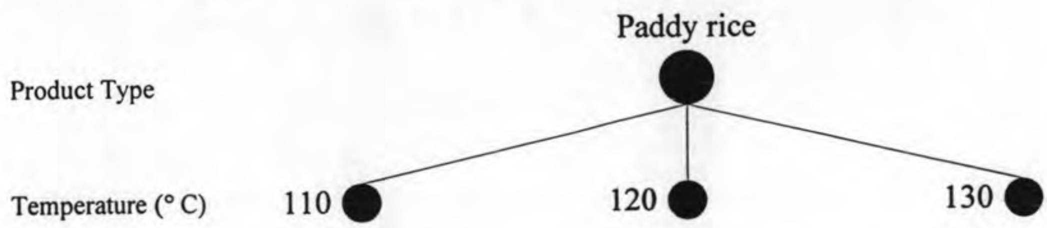

Figure 3.4 Drying time within a constant drying rate phase of paddy rice

(3) Drying with Falling Drying Rate Phase

In this phase, experiments are conducted to find the drying time for paddy rice. Drying temperature levels are varied at 55, 60, and 65°C. For each drying temperature level, drying times are specified at 15 hours. Moreover, each experiment is conducted with five replicates. All experiments of drying paddy rice are summarized in Figure 3.5.

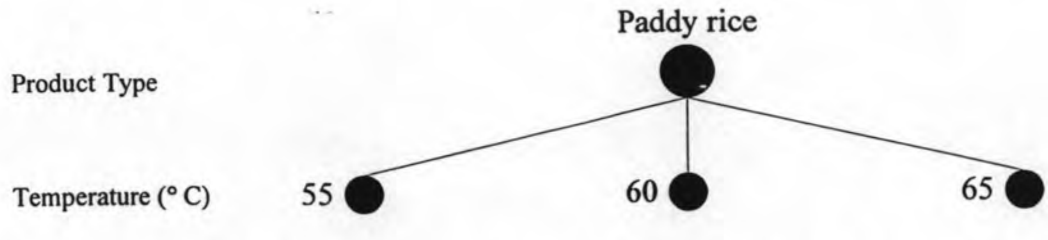

Figure 3.5 Drying time within falling drying rate phase of paddy rice

3.2.2 Cassava Chip

Cassava chip is transferred to the drying process with three drying phases. Firstly, cassava chip is heated within heating phase. Secondly, heated cassava chip is dried with a constant drying rate phase. Finally, dried cassava chip from the second phase is dried again with falling drying rate phase.

(1) Heating Phase

In this phase, experiments are conducted to find the heating time for cassava chip. Heating temperature levels are varied at 90, 100, and 110°C. For each heating temperature level, heating times are specified at 10 minutes. Moreover, each experiment is conducted with five replicates. All experiments of heating cassava chip are summarized in Figure 3.6.

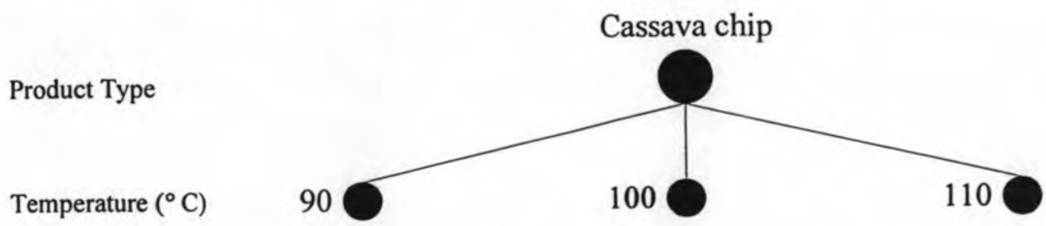

Figure 3.6 Heating time of cassava chip

(2) Drying with a Constant Drying Rate Phase

In this phase, experiments are conducted to find the drying time for cassava chip. Drying temperature levels are varied at 90, 100, and 110°C. For each drying temperature level, drying times are specified at 30 minutes. Moreover, each experiment is conducted with five replicates. All experiments of drying cassava chip are summarized in Figure 3.7.

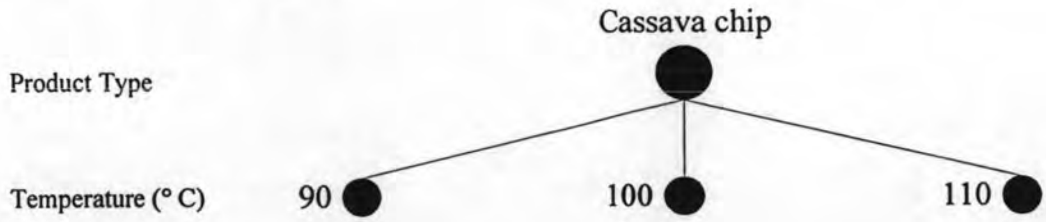

Figure 3.7 Drying time within a constant drying rate phase of cassava chip

(3) Drying with Falling Drying Rate Phase

In this phase, experiments are conducted to find the drying time for paddy rice. Drying temperature levels are varied at 90, 100, and 110°C. For each drying temperature level, drying times are specified at 20 minutes. Moreover, each experiment is conducted with five replicates. All experiments of drying cassava chip are summarized in Figure 3.8.

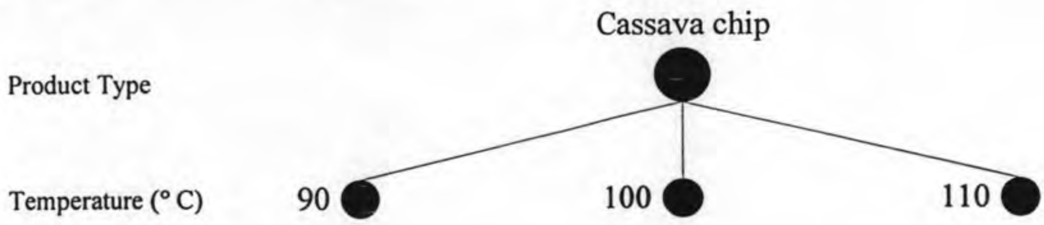

Figure 3.8 Drying time within falling drying rate phase of cassava chip

3.2.3 Tobacco

Tobacco is transferred to the drying process with three drying phases. Firstly, tobacco is heated within heating phase. Secondly, heated tobacco is dried with a constant drying rate phase. Finally, dried tobacco from the second phase is dried again with falling drying rate phase.

(1) Heating Phase

In this phase, experiments are conducted to find the heating time for tobacco. Heating temperature levels are varied at 55, 60, and 65°C. For each heating temperature level, heating times are specified at five minutes. Moreover, each experiment is conducted with five replicates. All experiments of heating tobacco are summarized in Figure 3.9.

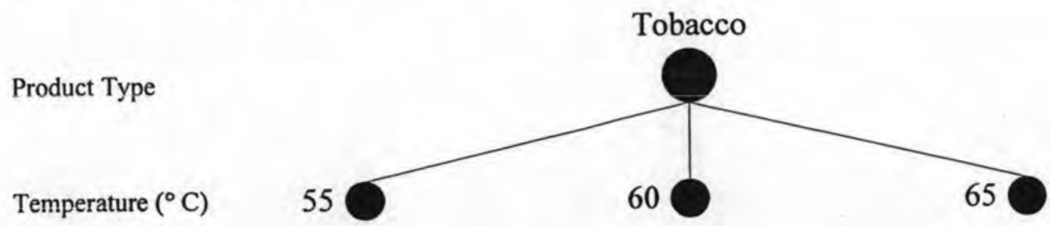

Figure 3.9 Heating time of tobacco

(2) Drying with a Constant Drying Rate Phase

In this phase, experiments are conducted to find the drying time for tobacco. Drying temperature levels are varied at 60, 65, and 70°C. For each drying temperature level, drying times are specified at 20 minutes. Moreover, each experiment is conducted with five replicates. All experiments of drying tobacco are summarized in Figure 3.10.

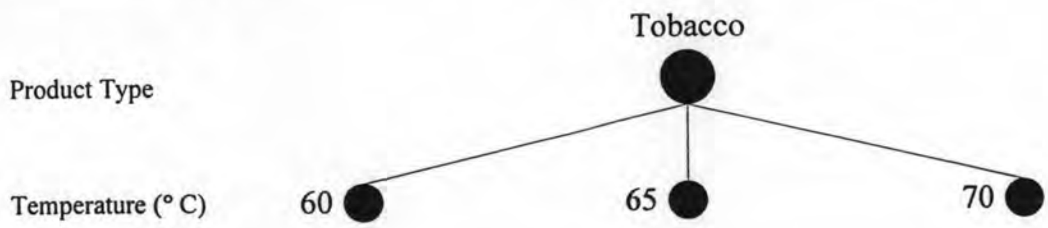

Figure 3.10 Drying time within a constant drying rate phase of tobacco

(3) Drying with Falling Drying Rate Phase

In this phase, experiments are conducted to find the drying time for tobacco. Drying temperature levels are varied at 45, 50, and 55°C. For each drying temperature level, drying times are specified at 10 minutes. Moreover, each experiment is conducted with five replicates. All experiments of drying tobacco are summarized in Figure 3.11.

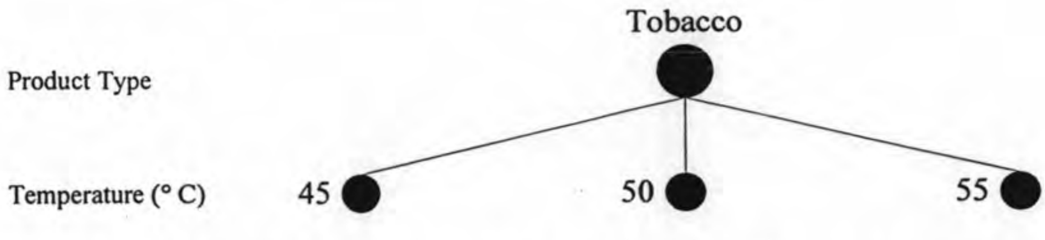

Figure 3.11 Drying time within falling drying rate phase of tobacco

3.2.4 Longan

Longan is transferred to the drying process with three drying phases. Firstly, longan is heated within heating phase. Secondly, heated longan is dried with a constant drying rate phase. Finally, dried longan from the second phase is dried again with falling drying rate phase.

(1) Heating Phase

In this phase, experiments are conducted to find the heating time for longan. Heating temperature levels are varied at 70, 75, and 80°C. For each heating temperature level, heating times are specified at 18 hours. Moreover, each experiment is conducted with five replicates. All experiments of heating longan are summarized in Figure 3.12.

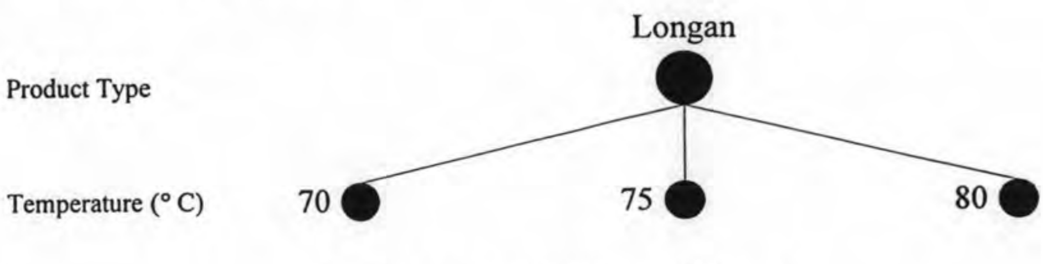

Figure 3.12 Heating time of longan

(2) Drying with a Constant Drying Rate Phase

In this phase, experiments are conducted to find the drying time for longan. Drying temperature levels are varied at 80, 85, and 90°C. For each drying temperature level, drying times are specified at 18 hours. Moreover, each experiment is conducted with five replicates. All experiments of drying longan are summarized in Figure 3.13.

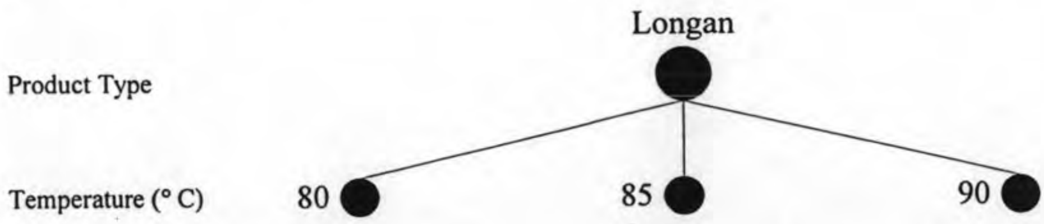

Figure 3.13 Drying time within a constant drying rate phase of longan

(3) Drying with Falling Drying Rate Phase

In this phase, experiments are conducted to find the drying time for longan. Drying temperature levels are varied at 80, 85, and 90°C. For each drying temperature level, drying times are specified at 12 hours. Moreover, each experiment is conducted with five replicates. All experiments of drying longan are summarized in Figure 3.14.

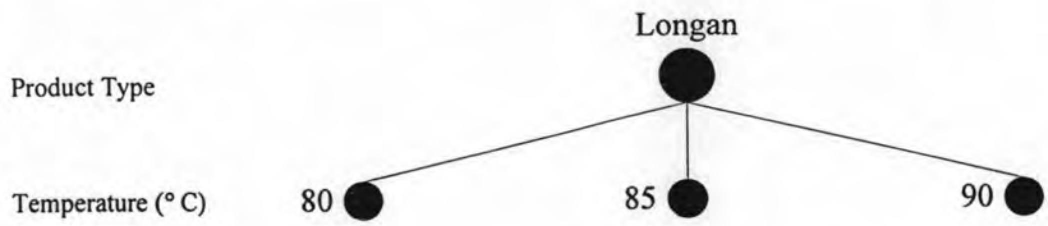

Figure 3.14 Drying time within falling drying rate phase of longan

3.3 Experimental Procedure for Quality Variation Management in Raw Material

In the agro-industry, the raw material is the first major source of the quality variation. Therefore, the raw material should be firstly managed to reduce its variety of the quality. In this step, a method for reducing the dried product quality variation from the variety of the agro-material is developed. The developed method is based on fuzzy c-means clustering. Experimental procedure of this step is shown as Figure 3.15.

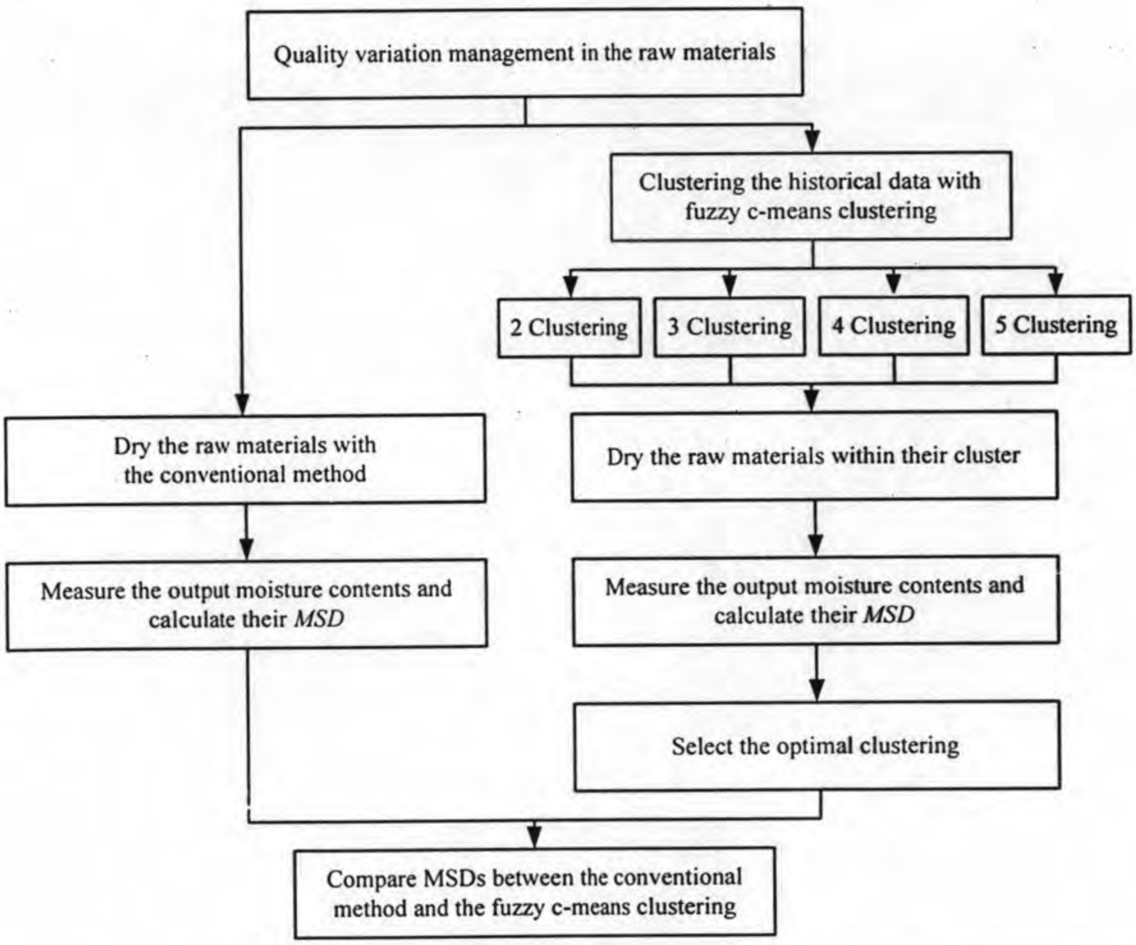

Figure 3.15 Experimental procedure for quality variation management in raw material

From the Figure 3.15, experiments are conducted with two groups. The first group is drying with the conventional method or without clustering. After drying, the dried products from the conventional method are measured in term of *MSD*.

The second group is drying with fuzzy c-means clustering. It begins with organizing the historical data from the traders into their clusters. The number of cluster is varied at 2, 3, 4, and 5 clustering in order to investigate behaviors of the dried product quality variation within various numbers of clusters. After clustering, the raw materials within each cluster are dried and measured *MSD* to evaluate the dried product quality variation. The algorithm of drying with fuzzy c-means clustering can be described as below.

Historical drying data are collected from traders. These data consist of two fields as the initial and output moisture contents with seventy-five samples. They are transformed into a 75×2 matrix called **X**. The first column of the matrix **X** is the initial moisture content and the second column is the output moisture content. The matrix **X** is used to cluster with fuzzy c-means clustering based on the minimization of an objective function as Equation (3.2). Fuzzy c-means clustering is carried out through an iterative optimization of the objective function in the Equation (3.2) with the update of the cluster center v_j and the membership μ_{ij} denoted as Equation (3.3) and (3.4) respectively.

$$J_m = \sum_{i=1}^{n}\sum_{j=1}^{c}\left(\mu_{ij}\right)^m \left\|x_i - v_j\right\|^2, \quad 1 \le m \le \infty \tag{3.2}$$

$$v_j = \frac{\sum_{i=1}^{n} \mu_{ij}^m \cdot x_i}{\sum_{i=1}^{n} \mu_{ij}^m} \tag{3.3}$$

$$\mu_{ij} = \frac{1}{\sum_{k=1}^{c}\left(\frac{\left\|x_i - v_j\right\|}{\left\|x_i - v_k\right\|}\right)^{\frac{2}{m-1}}}, \quad 2 \le m \le \infty \tag{3.4}$$

where

m = any real number greater than 1

μ_{ij} = the degree of membership of x_i in the cluster j

x_i = the ith of d-dimensional measured data

v_j = the d-dimension centre of the cluster j

c = the number of cluster

n = the number of samples

The measure of dissimilarity in the Equation (3.2) is the squared distance between each data point x_i and the cluster center v_j. This distance is weighted by the power of the membership degree of that point μ_{ij}^{m}. The value of the objective function in the Equation (3.2) is a measure of the total weighted within-group squared error incurred by the representation of the numbers of cluster defined by their centers v_j (Abnoyi and Feil, 2007).

From the Equation (3.2) to (3.4), fuzzy c-means clustering is performed to cluster the data with the following steps:

(1) Initialize $\mathbf{U} = [\mu_{ij}]$ matrix as $\mathbf{U}^{(0)}$.

(2) At k-step: calculate the centers vectors $\mathbf{V}^{(k)} = [v_j]$ with $\mathbf{U}^{(k)}$ by the Equation (3.3).

(3) Update $U^{(k)}$, $U^{(k+1)}$ by the Equation (3.4).

(4) If $||U^{(k+1))} - U^{(k)}|| < \varepsilon$, the objective function in the Equation (3.2) is also minimized then stop iteration; otherwise return to step 2. In this dissertation, ε is equaled to 10^{-5}.

However, this algorithm is performed by Matlab program release 2008a with fuzzy c-means clustering function or *fcm* function.

After clustering, the raw materials within their clusters are dried. Drying time is desired at a constant time, but drying temperature level can be adjusted by the decision of the operators who have high skill and long experience in the drying process. After drying, *MSD* of each drying experiment with fuzzy c-means clustering method is measured to evaluate the dried product quality variation. When all of *MSD*s are measured, the optimal number of cluster is selected with the minimum *MSD* to be the representative of fuzzy c-means clustering.

Finally, *MSDs* from the conventional method and from fuzzy c-means clustering are compared in order to ensure that fuzzy c-means clustering can be used to reduce the dried product quality variation from the conventional method.

3.4 Experimental Procedure for Quality Variation Management in Drying Process within Heating Phase

In previous step, the experimental procedure for clustering the raw materials into their clustered is already described. In this step, the experimental procedure for conducting experiments of quality variation management in drying process within heating phase is presented.

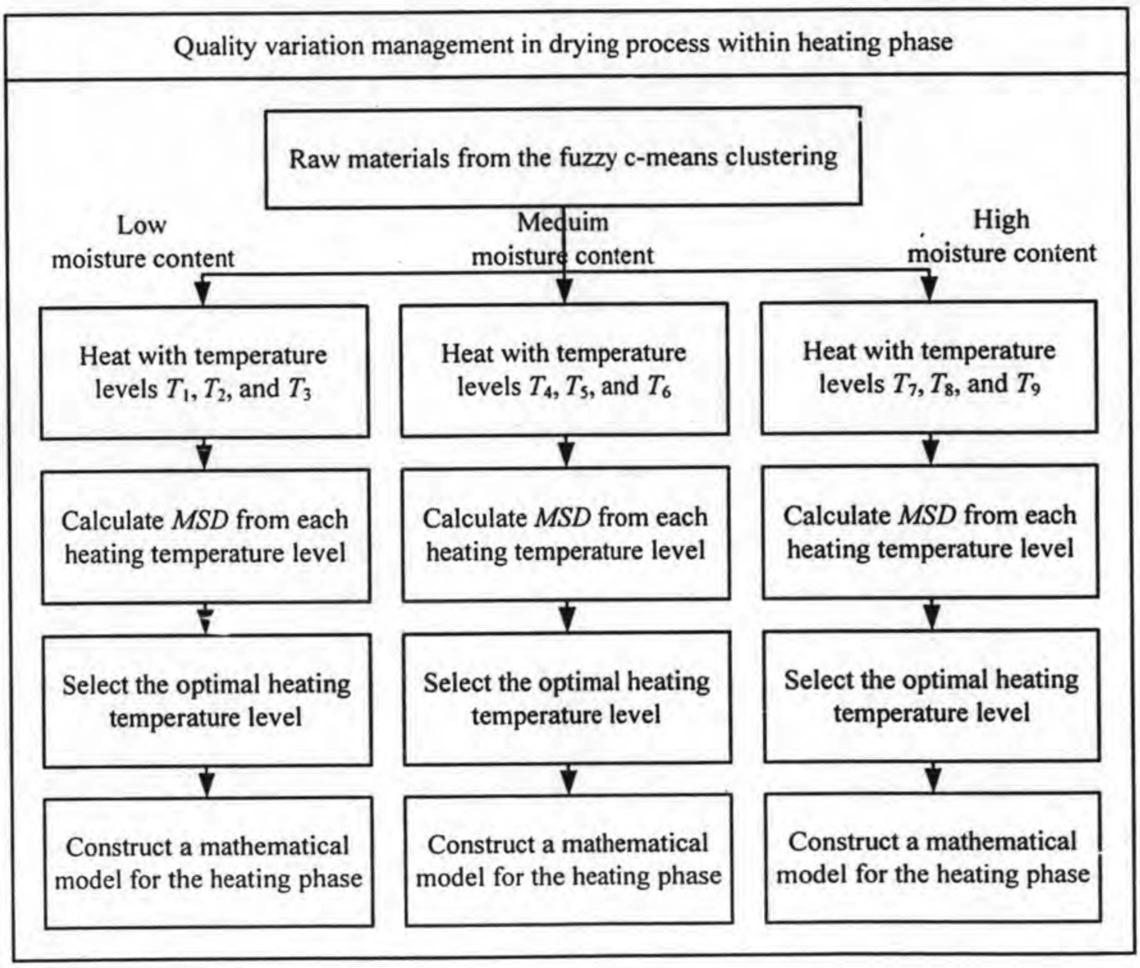

Figure 3.16 Experimental procedure for quality variation management in drying process heating phase

After the optimal number of clustering is selected, the raw materials are organized into three clusters with ranges of the initial moisture content. From Figure 3.16, three clusters can be listed as low, medium, and high initial moisture contents. Within low initial moisture content cluster, the raw materials are heated by varying temperature levels from T_1, T_2, and T_3. After heating with various temperature levels, *MSD* from each heating temperature level is measured to select the optimal heating temperature level with minimum *MSD*. Likewise, the raw materials within medium and high initial moisture contents are also heated by three levels of the heating temperature. After heating, *MSD* for each heating is also measured to select the optimal heating temperature level with minimum *MSD*. Finally, mathematical models are constructed to express relationships between the moisture content and heating time.

3.4.1 Paddy Rice

During heating phase, paddy rice is heated within 30 seconds. The experiments of heating paddy rice are conducted by varying temperature levels shown as Figure 3.17. Within low and medium initial moisture content, heating temperature levels are varied at 55, 60, and 65°C, while the raw materials within high moisture content are heated at 60, 63, and 65°C. Moreover, each experiment is conducted with 15 replications.

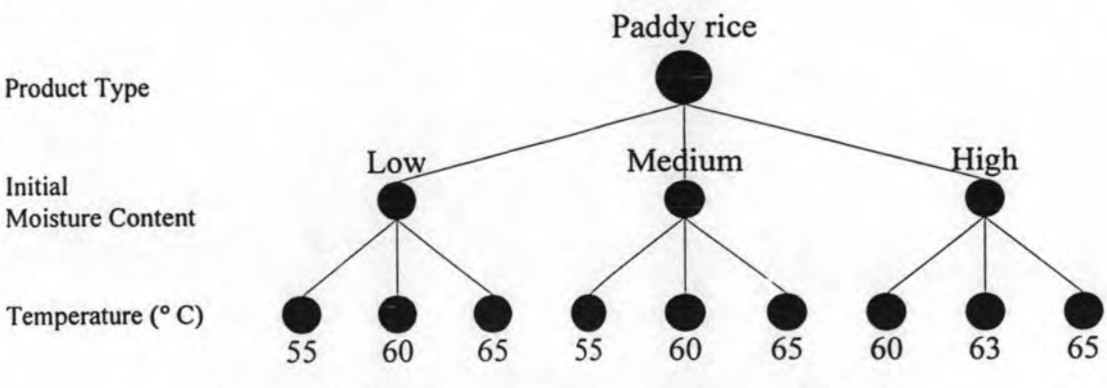

Figure 3.17 Heating temperature levels of paddy rice

3.4.2 Cassava Chip

During heating phase, cassava chip is heated within five minutes. The experiments of heating cassava chip are conducted by varying temperature levels shown as Figure 3.18. Within low moisture content, cassava chip is heated at 90, 95, and 100°C. Within medium moisture content, heating temperature levels are varied at 90, 100, and 110°C. Within high moisture content, cassava chip is heated at 105, 110, 115°C. Moreover, each experiment is conducted with five replications.

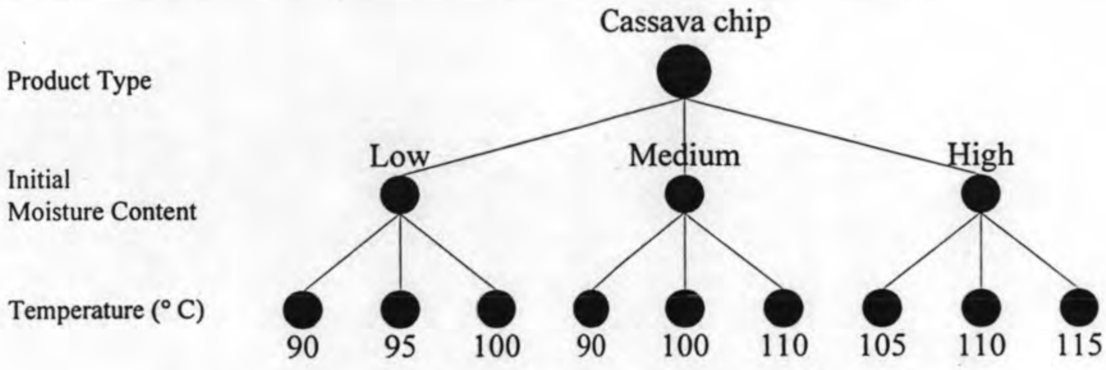

Figure 3.18 Heating temperature levels of cassava chip

3.4.3 Tobacco

During heating phase, tobacco is heated within three minutes. The experiments of heating tobacco are conducted by varying temperature levels shown as Figure 3.19. The raw materials within low moisture content are heated at 45, 50, and 55°C. The raw materials within medium moisture content are heated at 50, 55, and 60°C. Finally, the raw materials within high moisture content are heated at 55, 60, and 65°C. Moreover, each experiment is conducted with 15 replications.

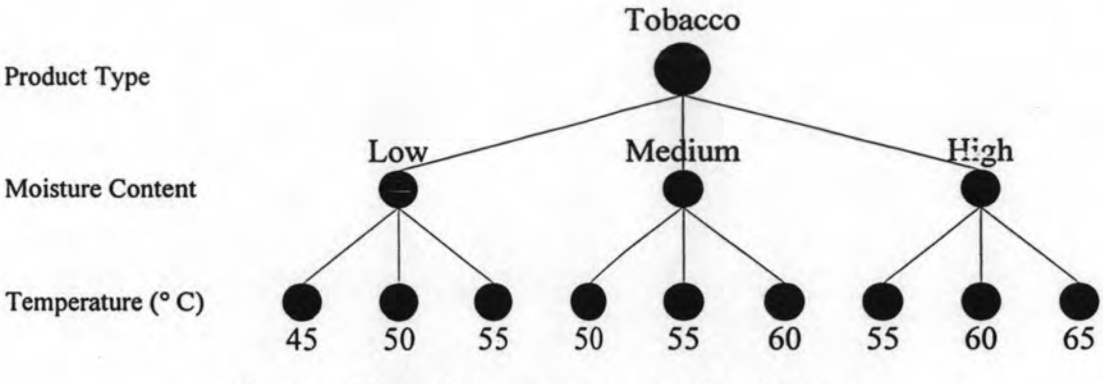

Figure 3.19 Heating temperature levels of tobacco

3.4.4 Longan

During heating phase, longan is heated within 15 hours. The experiments of heating longan are conducted by varying temperature levels shown as Figure 3.20. Longan within low moisture content is heated at 65, 70, and 75°C, while longan within medium moisture content is heated at 70, 75, and 80°C. Finally, longan within high moisture content is heated at 75, 77, and 80°C. Moreover, each experiment is conducted with five replications.

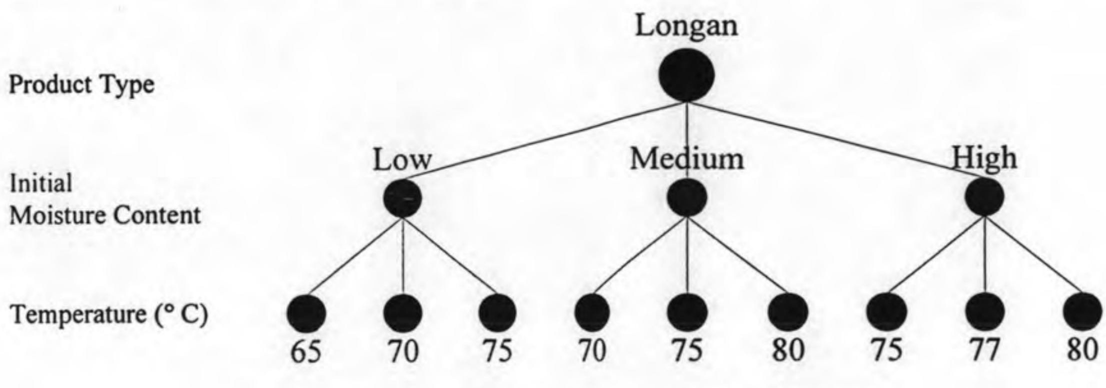

Figure 3.20 Heating temperature levels of longan

3.5 Experimental Procedure for Quality Variation Management in Drying Process within a Constant Drying Rate Phase

After clustered raw materials are heated with the experiment in Section 3.4, they are transferred to another phase of the drying process. During this phase, heated raw materials are dried with a constant drying rate. Therefore, the methodology for conducting experiments of quality variation management in drying process within a constant drying rate phase is presented as shown in Figure 3.21.

From the Figure 3.21, drying temperature is varied with three levels for each cluster of the raw material. After drying, *MSD* for each drying with a temperature level is measured to select the optimal drying temperature level. This optimal drying temperature level is based on minimum value of *MSD*.

In this phase, the raw materials are dried to their targets of the moisture content in Table 3.1. These targets were found by previous researches. Therefore, the aim of this step is to find the optimal drying temperature level which can be used to dry the raw materials to their targets of the moisture content. Moreover, mathematical models are constructed to represent relationships between the moisture content and drying time within the second drying phase.

Table 3.1 Target of moisture content for drying process within a constant drying rate phase

Product	Target of Moisture Content (% w.b.)	Reference
Paddy rice	19.0	(Sopcnıonnarit, 1999)
Cassava chip	30.0	(Salgado, et al., 1994)
Tobacco	14.0	(Legros, et al., 1994)
Longan	73.0	(National Food Institute, 1998)

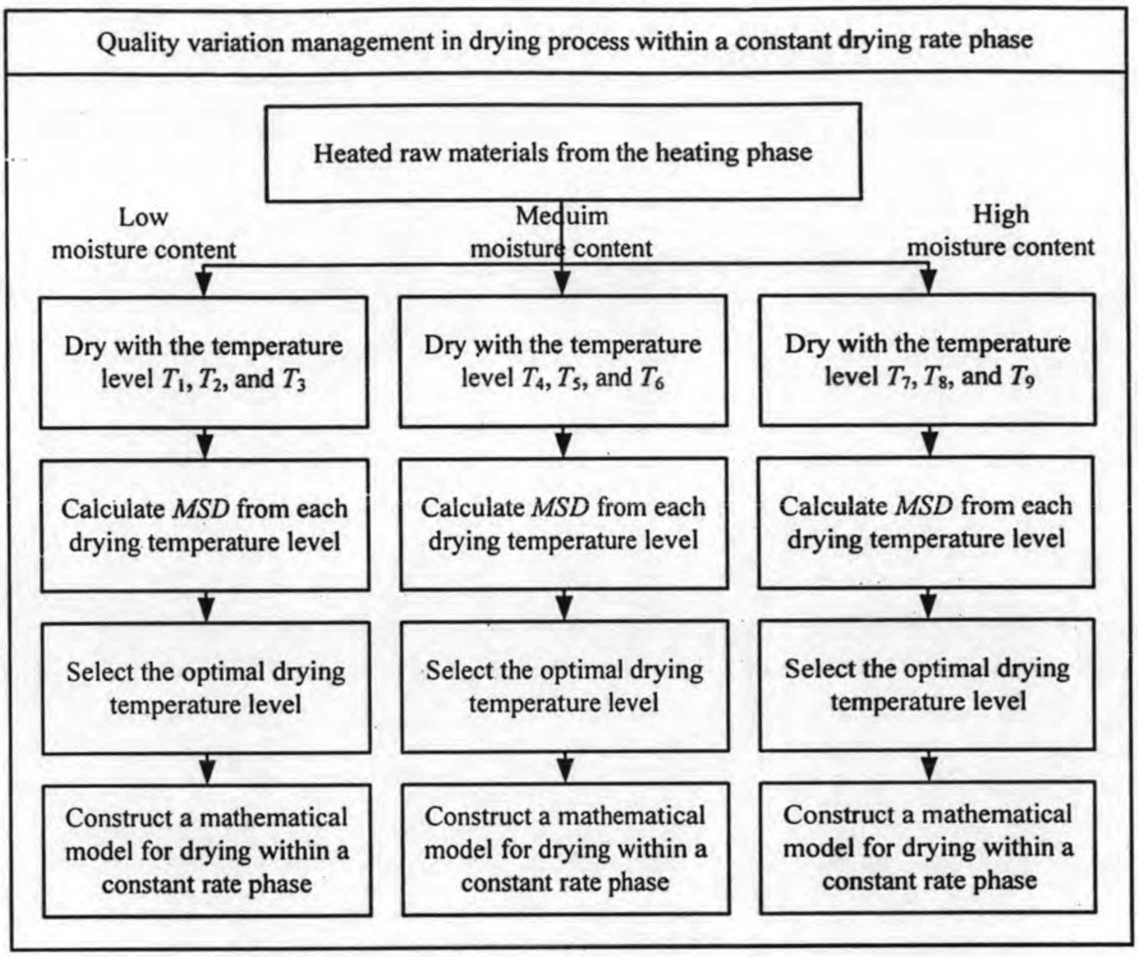

Figure 3.21 Experimental procedure for quality variation management in drying process within a constant drying rate phase

3.5.1 Paddy Rice

In this phase, paddy rice from heating phase is dried within five minutes. Within low initial moisture content, paddy rice is dried by varying levels of drying temperature at 100, 110, and 120°C. Within medium initial moisture content, temperature levels for drying paddy rice are varied at 115, 120, and 125°C. For paddy rice within a range of high initial moisture content, it is dried by varying levels of drying temperature at 120, 125, and 130°C. All varying levels of drying temperature are summarized in Figure 3.22. Moreover, each experiment is conducted with 15 replications.

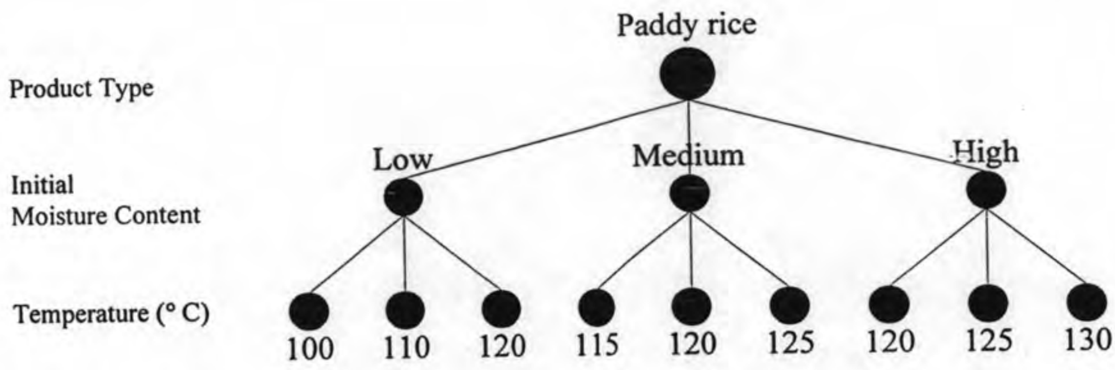

Figure 3.22 Drying temperature levels of paddy rice for a constant drying rate phase

3.5.2 Cassava Chip

In this phase, cassava chip from heating phase is dried within 20 minutes. Within low initial moisture content, cassava chip is dried by varying levels of drying temperature at 90, 100, and 110°C. Within medium initial moisture content, temperature levels for drying cassava chip are varied at 95, 100, and 105°C. For cassava chip within a range of high initial moisture content, it is dried by varying levels of drying temperature at 105, 110, and 115°C. All varying levels of drying temperature are summarized in Figure 3.23. Moreover, each experiment is conducted with five replications.

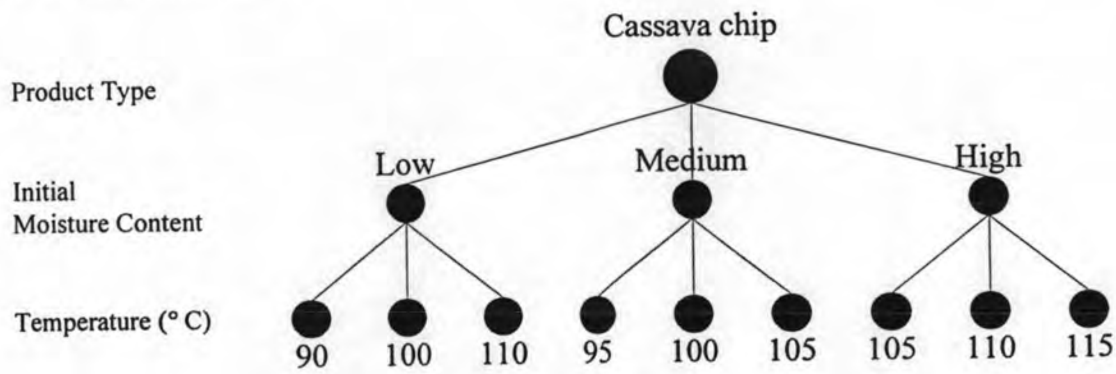

Figure 3.23 Drying temperature levels of cassava chip for a constant drying rate phase

3.5.3 Tobacco

In this phase, tobacco from heating phase is dried within 10 minutes. Within low initial moisture content, tobacco is dried by varying levels of drying temperature at 55, 60, and 65°C. Within medium initial moisture content, temperature levels for drying tobacco are varied at 60, 65, and 70°C. For tobacco within a range of high initial moisture content, it is dried by varying levels of drying temperature at 65, 70, and 75°C. All varying levels of drying temperature are summarized in Figure 3.24. Moreover, each experiment is conducted with 15 replications.

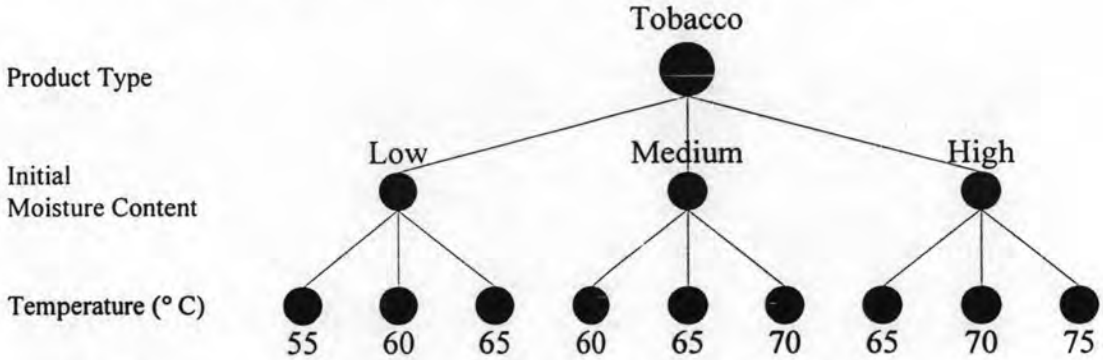

Figure 3.24 Drying temperature levels of tobacco for a constant drying rate phase

3.5.4 Longan

In this phase, longan from heating phase is dried within 15 hours. Within low initial moisture content, longan is dried by varying levels of drying temperature at 65, 70, and 75°C. Within medium initial moisture content, temperature levels for drying longan are varied at 80, 85, and 88°C. For longan within a range of high initial moisture content, it is dried by varying levels of drying temperature at 85, 88, and 90°C. All varying levels of drying temperature are summarized in Figure 3.25. Moreover, each experiment is conducted with five replications.

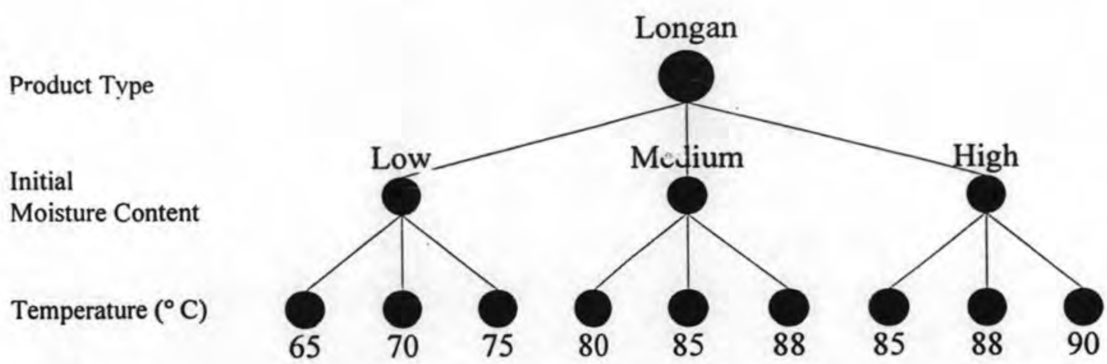

Figure 3.25 Drying temperature levels of longan for a constant drying rate phase

3.6 Experimental Procedure for Quality Variation Management in Drying Process within Falling Drying Rate Phase

In Section 3.5, the experimental procedure for quality variation management in drying process within a constant drying rate phase is already described. In this section, the experimental procedure for quality variation management in drying process within falling drying rate phase is also described as shown in Figure 3.26. The aim of the experimental procedure in this section is to find the optimal drying temperature level to dry the raw materials within this phase.

From the Figure 3.26, drying temperature is varied with three levels. After drying, *MSD* for each drying with a temperature level is measured to select the optimal drying temperature level. This optimal drying temperature level is based on minimum value of *MSD*.

In this phase, the raw materials are dried to their targets of the moisture content in Table 3.2. These targets were found by previous researches. Therefore, the aim of this step is to find the optimal drying temperature level which can be used to dry the raw materials to their targets of the moisture content. Moreover, mathematical models are constructed to represent relationships between the moisture content and drying time within the last drying phase.

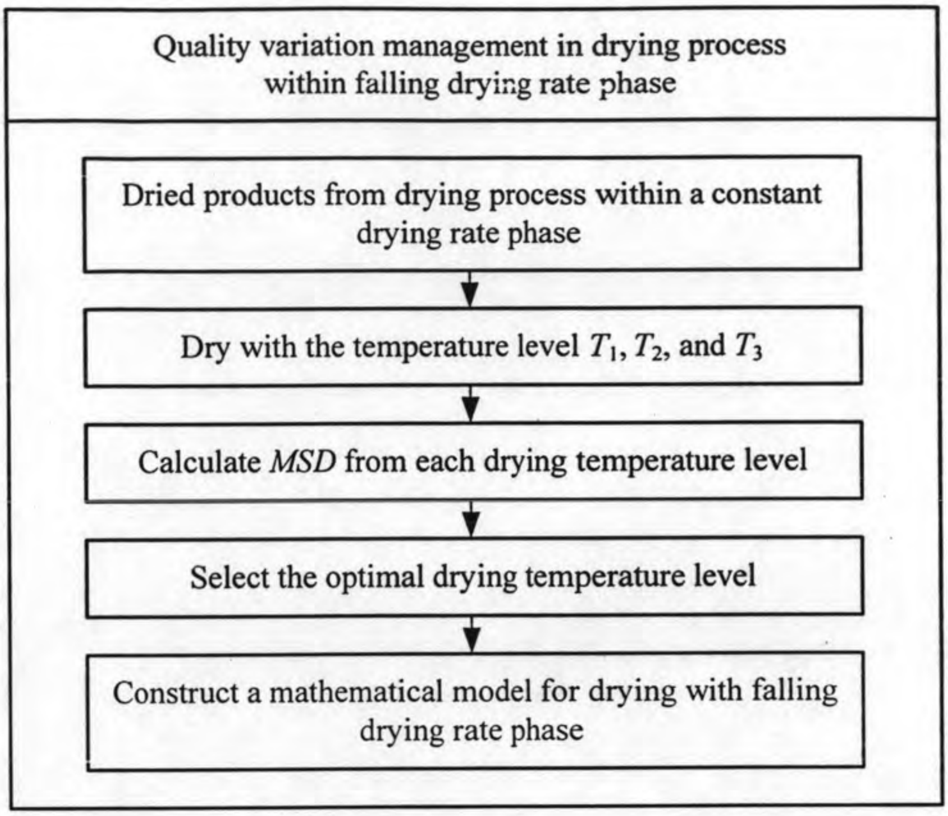

Figure 3.26 Experimental procedure for quality variation management in drying process within falling drying rate phase

Table 3.2 Target of moisture content for drying process within falling drying rate phase

Product	**Target of Moisture Content (% w.b.)**	**Reference**
Paddy rice	14.0	(Soponronnarit, 1999)
Cassava chip	14.0	(Salgado, et al., 1994)
Tobacco	12.5	(Legros, et al., 1994)
Longan	18.0	(National Food Institute, 1998)

3.6.1 Paddy Rice

The moisture content of paddy rice after drying within the second phase is in a range of 19.0% w.b. In this phase, paddy rice at 19.0% w.b. is dried within 12 hours with varying levels of temperature at 55, 60, and 65°C (Figure 3.27). Moreover, each experiment is conducted with 15 replications.

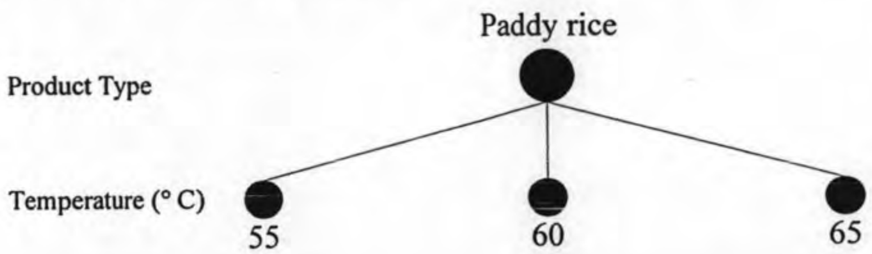

Figure 3.27 Drying temperature levels of paddy rice for falling drying rate phase

3.6.2 Cassava Chip

The moisture content of cassava chip after drying within the second phase is in a range of 30.0% w.b. In this phase, cassava chip at 30.0% w.b. is dried within 15 minutes with varying levels of temperature at 95, 100, and 105°C (Figure 3.28). Moreover, each experiment is conducted with five replications.

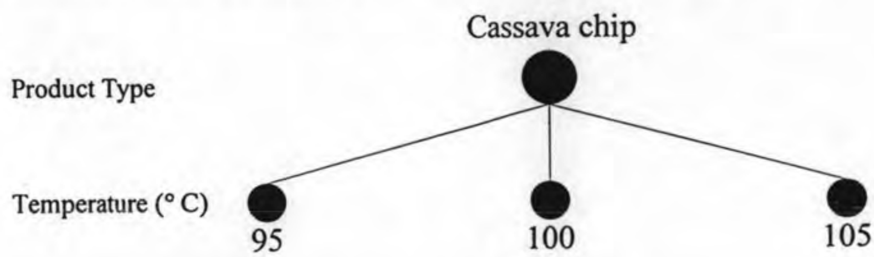

Figure 3.28 Drying temperature levels of cassava chip for falling drying rate phase

3.6.3 Tobacco

The moisture content of tobacco after drying within the second phase is in a range of 14.0% w.b. In this phase, tobacco at 14.0% w.b. is dried within five minutes with varying levels of temperature at 45, 50, and 55°C (Figure 3.29). Moreover, each experiment is conducted with 15 replications.

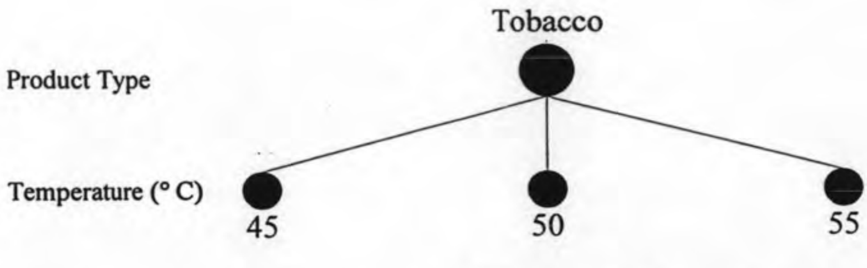

Figure 3.29 Drying temperature levels of tobacco for falling drying rate phase

3.6.4 Longan

The moisture content of longan after drying within the second phase is in a range of 73.0% w.b. In this phase, tobacco at 73.0% w.b. is dried within 10 hours with varying levels of temperature at 80, 85, and 90°C (Figure 3.30). Moreover, each experiment is conducted with five replications.

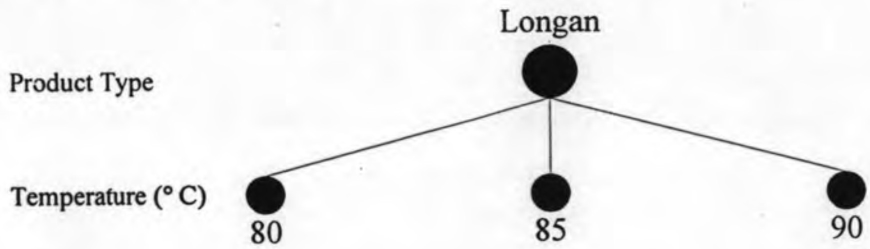

Figure 3.30 Drying temperature levels of longan for falling drying rate phase

3.7 Validation

After finishing all of drying experiments, the optimal drying temperature levels for each drying phase are already established. To ensure that these optimal drying temperature levels can minimize the dried product quality variation or *MSD*, implementation with real drying process industry is necessary to validate. Therefore, the aim of this step is to validate that the optimal drying temperature levels from all experiments can be used to minimize the dried product quality variation within the real situations.

Experimental procedure in this step is to compare *MSD* between from the mathematical models and from the implementation. If the percentage of the difference MSD between from the mathematical models and from the implementation is less than 5.0%, the optimal drying temperature levels can be used for real drying process industry.

3.8 Conclusion

In this chapter, the methodology for this dissertation is presented. It is classified into seven steps as defining the problem, experimental procedure for determining the drying time, experimental procedure for quality variation management in raw material, experimental procedure for quality variation management in drying process within heating phase, experimental procedure for quality variation management in drying process within a constant drying rate phase, experimental procedure for quality variation management in drying process within falling drying rate phase, and validation.

In the first step, the problem is defined to scope the study area and variables. The dried product quality variation is the major problem for drying process in Thai agro-industry. This quality variation can be measured in term of *MSD*, a powerful statistical measure for evaluating variation from the quality target. Moreover, four types of dried product are selected to study as paddy rice, cassava chip, tobacco, and longan.

In the second step, drying time for each phase is investigated. For each drying phase, drying temperature is varied with three levels and each drying temperature level is conducted with four levels of drying time. After drying, *MSD* for each experiment is measured to evaluate the dried product quality variation. Drying time is selected with the minimum value of *MSD*.

After the drying times can be selected, experimental procedure for quality variation management in raw material is presented in the third step. The aim of this step is to reduce the variety of quality of the raw material in order to reduce the dried product quality variation. In this step, fuzzy c-means clustering is used to organize the raw materials with same characteristics to their clusters. The number of clustering is varied at 2, 3, 4, and 5. After clustering, the raw materials within their clusters are dried and measured *MSD*. The optimal number of clustering is selected from the minimum *MSD*.

When the optimal number of clustering can be selected, clustered raw materials are heated within heating phase as the first drying phase. Experimental procedure for quality variation management in drying process within heating phase is described in the fourth step. Furthermore, the aim of this step is to find the optimal heating temperature level for each cluster of the raw material. For heating each cluster, heating temperature is varied with three levels and *MSD* is measured. After that, the optimal heating temperature level for each cluster is selected from the minimum *MSD*.

In the fifth step, experimental procedure for quality variation management in drying process within a constant drying rate phase is presented. The aim of this step is to find the optimal drying temperature level to dry the raw materials after heating within the first drying phase. For drying each cluster of heated raw materials, drying temperature is varied with three levels and *MSD* is measured. After that, the optimal drying temperature level for each cluster is selected from the minimum *MSD*.

After drying with a constant drying rate, experimental procedure for quality variation management in drying process within falling drying rate phase is presented in the sixth step. The aim of this step is to find the optimal drying temperature level to dry the raw materials after drying within the second drying phase. For drying the raw materials, drying temperature is varied with three levels and *MSD* is measured. After that, the optimal drying temperature level is selected from the minimum *MSD*.

In the last step, all of results are implemented with the real drying process in Thai agro-industry to validate that the optimal drying temperature levels from the study can be used to reduce and minimize the dried product quality variation.