CHAPTER V

QUALITY VARIATION MANAGEMENT IN RAW MATERIAL

Raw material from the agricultural sector is the most major source of the dried product quality variation. It is very difficult to control the quality of the raw material because it depends on several uncontrolled factors such as climate, thin soils, land fragmentation, and seasonality. These factors cause the variety of the raw material. To improve the quality of the dried product, this variety has to be managed during drying in order to minimize the dried product quality variation. Therefore, the aim of this chapter is to manage the variety of the raw material in order to minimize the dried product quality variation (Figure 5.1).

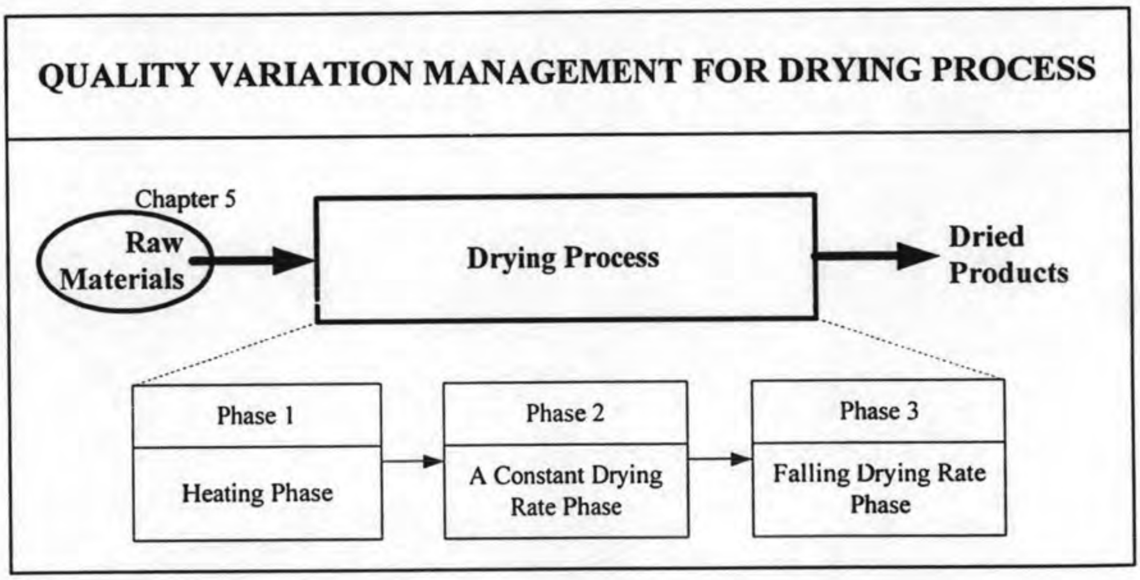

Figure 5.1 Scope of quality variation management in raw material

Clustering technique is a method used to reduce the variety of the raw material. It is used to classify any objects according to similarities among them and to organize them into their clusters. This technique is classified into two methods as hard clustering and fuzzy clustering. Hard clustering is a method based on classical set theory. It requires that an object either does or does not belong to a cluster. While fuzzy clustering is a method allowing the objects to belong several clusters simultaneously with different degrees of membership.

For the raw material from the agricultural sector, the moisture content is an inherent characteristic which is fuzziness. This characteristic can be on the boundaries between several clusters. It is not forced to fully to one of the clusters, but rather than are assigned membership degrees between 0 and 1 indicating their partial memberships. Hence, fuzzy clustering is the suitable method for reducing the variety of the raw material in the drying process. Moreover, the algorithm of fuzzy clustering used in this dissertation is fuzzy c-means clustering.

The outline of this chapter is organized into five sections. In Section 5.1 to 5.4, experimental results of paddy rice, cassava chip, tobacco, and longan are explained and discussed respectively. In each section, results of drying with the conventional method and fuzzy c-means clustering method are consisted. Moreover, comparison the dried product quality variation from between the conventional method and fuzzy c-means clustering method is also shown in each section. Finally, all experimental results are concluded in Section 5.5.

5.1 Experimental Results of Paddy Rice

Rice is the most important food for a large part of the human life. Moreover, it is very palatable and is the only cereal which can simply be boiled and eaten without disintegrating into mush (Bray, 1986). However, paddy rice is typically harvested at higher moisture content than acceptable for long-term safe storage. Therefore, it is necessary to be dried to reduce the moisture content to an acceptable range.

In this dissertation, the initial moisture content of paddy rice is in a range of 22-29% w.b. The moisture content after drying is desired to 14.0% w.b. From this target, *MSD* of paddy rice after drying can be simplified into Equation (5.1).

$$MSD = \frac{1}{n}\sum_{i=1}^{n}(y_i - 14)^2 \qquad (5.1)$$

where

y_i = the measured moisture content of paddy rice after drying

n = the numbers of sample size

5.1.1 Conventional Method

Thirty-five samples of paddy rice are dried with the conventional method. After drying, the product quality variation in term of *MSD* is measured. Its value is 3.655 (% w.b.)^2 greater than zero. It means that there is high quality variation of drying paddy rice. Furthermore, scatterplot between the output and the initial moisture content of drying paddy rice with the conventional method is shown as Figure 5.2. From the Figure 5.2, the drying data scatter widely. This means that the quality of dried paddy rice cannot be controlled by the conventional method.

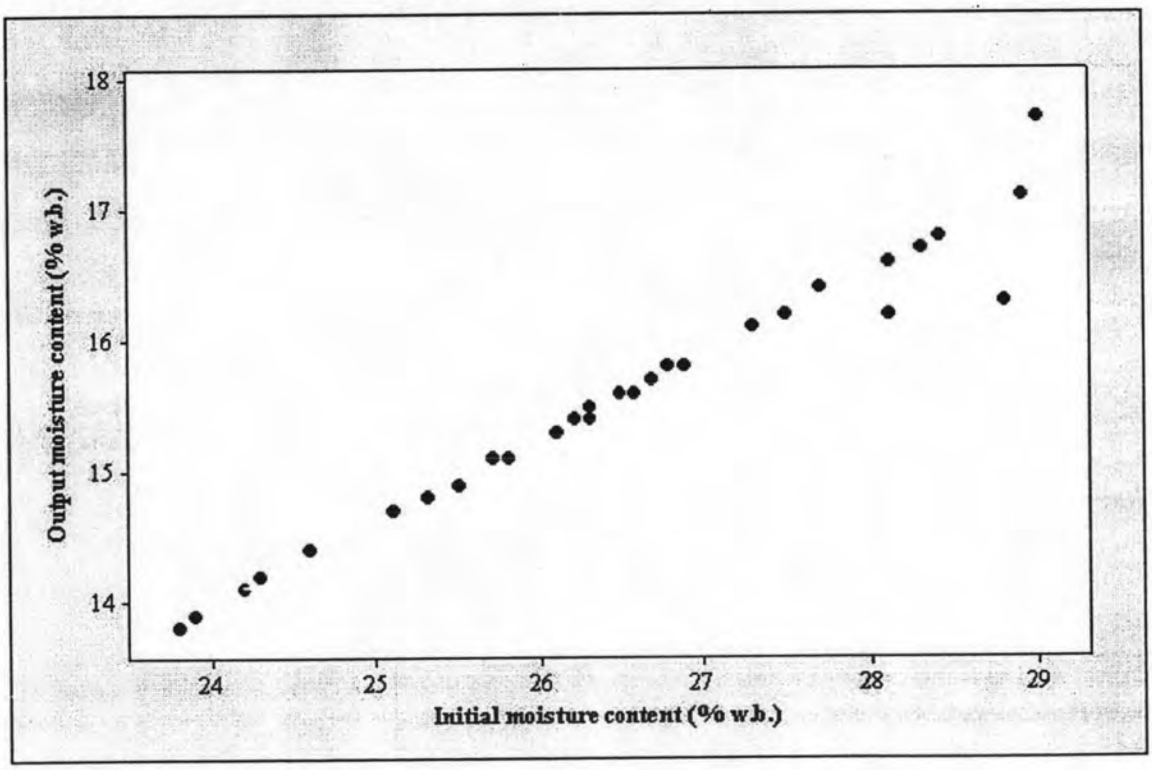

Figure 5.2 Scatterplot of output and initial moisture contents of paddy rice with the conventional method

5.1.2 Fuzzy C-Means Clustering Method

From the methodology in the Chapter 3, seventy-five paddy samples from drying historical data are used to cluster by fuzzy c-means clustering. The number of clustering is varied at 2, 3, 4, and 5 clusters. Clustering results from Matlab with *fcm* function are illustrated in Table 5.1.

Table 5.1 Clustering result of paddy rice with the initial moisture content

Clustering	Range of initial moisture content in the i^{th} cluster				
	1	2	3	4	5
2	22.1-26.6	26.7-29.0	-	-	-
3	22.1-25.3	25.4-27.0	27.1-29.0	-	-
4	22.1-25.4	25.5-27.0	27.1-27.7	27.8-29.0	-
5	22.1-25.3	25.4-26.6	26.7-27.6	27.7-28.3	28.4-29.0

The results from the Table 5.1 are used to be criteria for clustering the raw materials into their clusters. After clustering, paddy rice is dried within its cluster and measured *MSD* for evaluating the dried product quality variation. Finally, the optimal number of clustering is selected with the minimum value of *MSD*.

(1) 2 clustering

Thirty-five samples of paddy rice are clustered into two clusters with clustering result from the Table 5.1. Paddy rice in the first cluster is in a range of 22.1-26.6% w.b. (low initial moisture content) and paddy rice in the second cluster is in a range of 26.7-29.0% w.b. (high initial moisture content). After clustering, paddy rice in both clusters is dried within its cluster. Moreover, scatterplot between the output and the initial moisture content of drying paddy rice with the 2 clustering is shown as Figure 5.3.

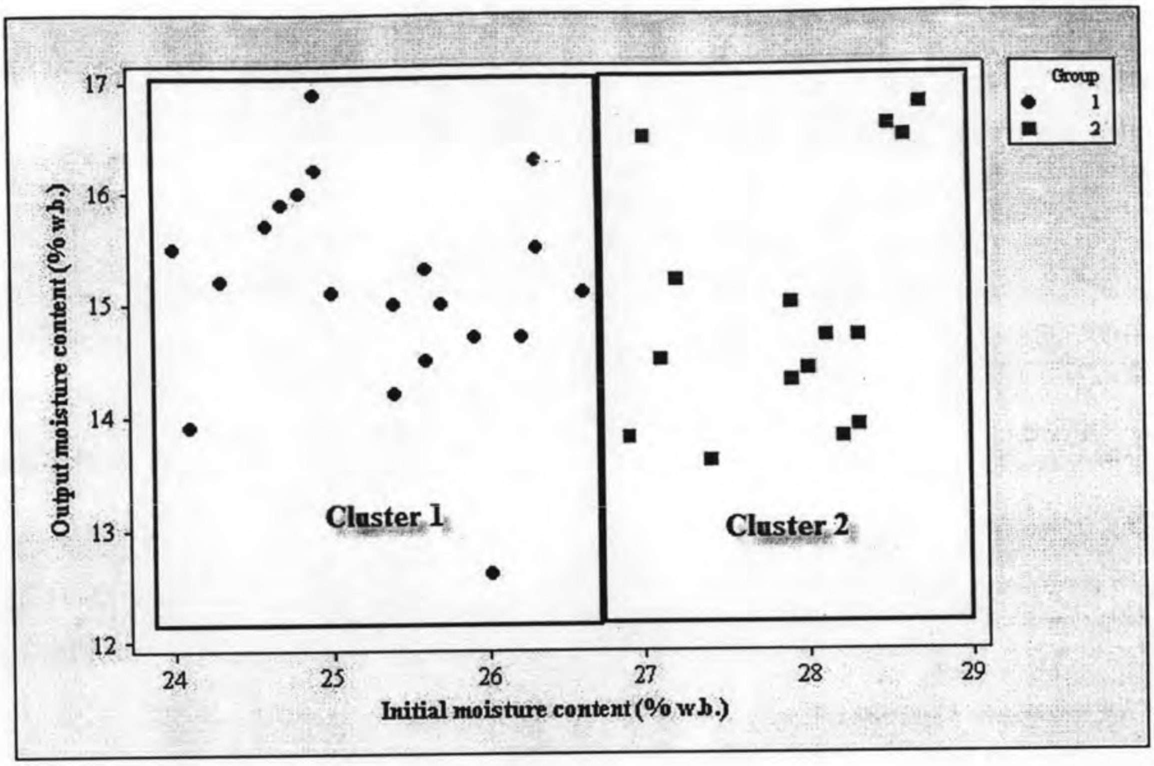

Figure 5.3 Scatterplot of output and initial moisture contents of paddy rice with 2-clustering method

From the Figure 5.3, the scatterplot of the cluster 1 is wider than the cluster 2. It means that drying within low initial moisture content is more difficult than high initial moisture content. However, *MSD* from drying with 2 clustering is 2.160 $(\% \text{ w.b.})^2$.

(2) 3 clustering

Thirty-five samples of paddy rice are clustered into three clusters with clustering result from the Table 5.1. Paddy rice in the first cluster is in a range of 22.1-25.3% w.b. (low initial moisture content), paddy rice in the second cluster is in a range of 25.4-27.0% w.b. (medium initial moisture content), and paddy rice in the third cluster is in a range of 27.1-29.0% w.b. (high initial moisture content). After clustering, paddy rice is dried within its cluster. Moreover, scatterplot between the output and the initial moisture content of drying paddy rice with the 3 clustering is shown as Figure 5.4.

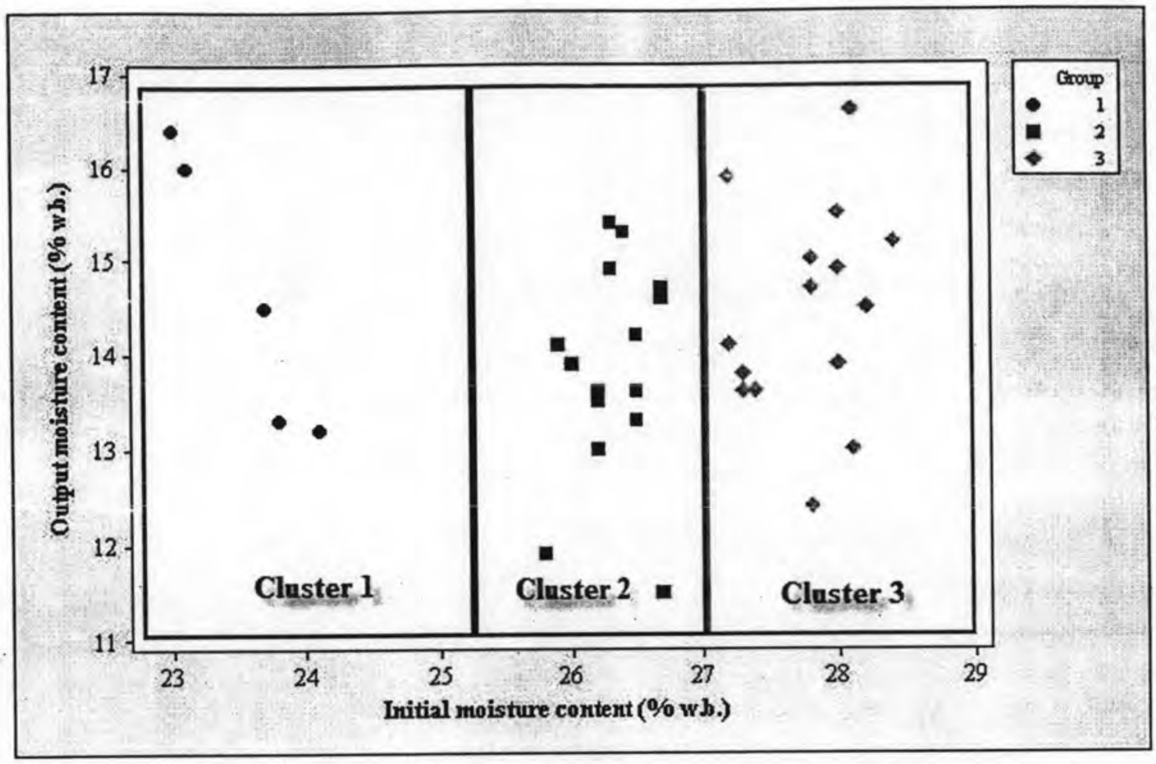

Figure 5.4 Scatterplot of output and initial moisture contents of paddy rice with 3-clustering method

From the Figure 5.4, the scatterplot of the cluster 1 and the cluster 3 are wider than the cluster 2. It means that drying within low and high initial moisture contents are more difficult than medium initial moisture content. However, *MSD* from drying with 3 clustering is 1.422 (% w.b.)^2.

(3) 4 clustering

Thirty-five samples of paddy rice are clustered into four clusters with clustering result from the Table 5.1. Paddy rice in the first cluster is in a range of 22.1-25.4% w.b. (lower initial moisture content), paddy rice in the second cluster is in a range of 25.5-27.0% w.b. (low initial moisture content), paddy rice in the third cluster is in a range of 27.1-27.7% w.b. (medium initial moisture content), and paddy rice in the fourth cluster is in a range of 27.7-29.0% w.b. (high initial moisture content). After clustering, paddy rice is dried within its cluster. Moreover, scatterplot between the output and the initial moisture content of drying paddy rice with the 4 clustering is shown as Figure 5.5.

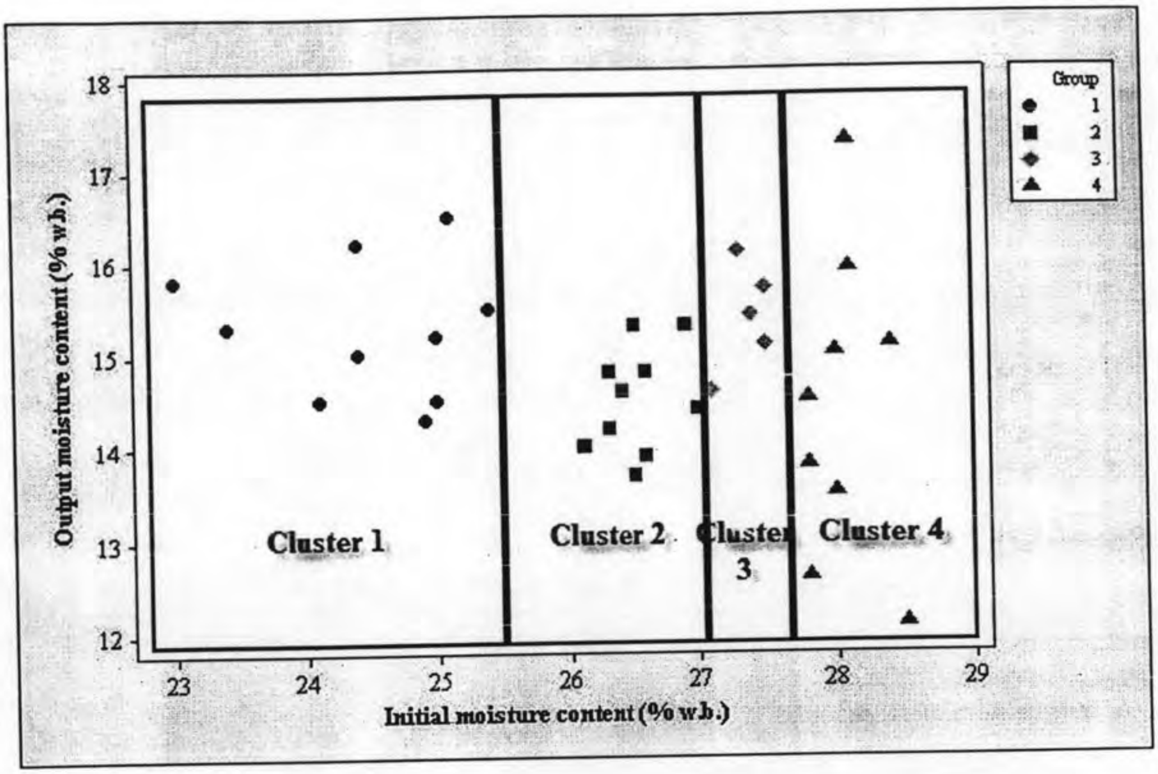

Figure 5.5 Scatterplot of output and initial moisture contents of paddy rice with 4-clustering method

From the Figure 5.5, the scatterplot of the cluster 3 is the narrowest than other clusters. It means that drying within medium initial moisture content can be controlled while dryings within other clusters are very difficult to control. However, *MSD* from drying with 4 clustering is 1.723 (% w.b.)^2.

(4) 5 clustering

Thirty-five samples of paddy rice are clustered into five clusters with clustering result from the Table 5.1. Paddy rice in the first cluster is in a range of 22.1-25.3% w.b. (lower initial moisture content), paddy rice in the second cluster is in a range of 25.4-26.6% w.b. (low initial moisture content), paddy rice in the third cluster is in a range of 26.7-27.6% w.b. (medium initial moisture content), paddy rice in the fourth cluster is in a range of 27.7-28.3% w.b. (high initial moisture content), and paddy rice in the fifth cluster is in a range of 28.4-29.0% w.b. (high initial moisture content). After clustering, paddy rice is dried within its cluster.

Moreover, scatterplot between the output and the initial moisture content of drying paddy rice with the 5 clustering is shown as Figure 5.6.

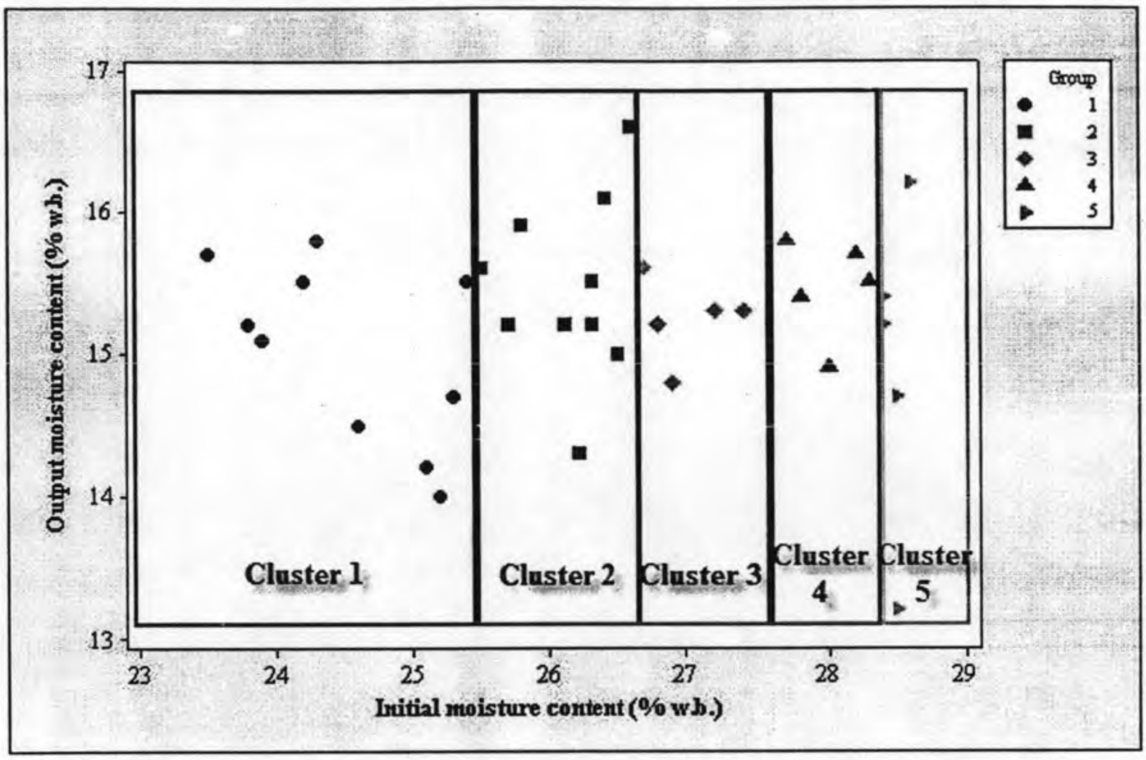

Figure 5.6 Scatterplot of output and initial moisture contents of paddy rice with 5-clustering method

From the Figure 5.6, the scatterplot of the cluster 1 is the widest than other clusters. It means that drying within lower initial moisture content is the most difficult to control than other clusters. However, *MSD* from drying with 5 clustering is 1.723 (% w.b.)^2.

5.1.3 Comparison between Conventional and Fuzzy C-Means Clustering Methods

MSD from drying with the conventional and with fuzzy c-means clustering methods are compared in this section. ANOVA is carried out to ensure that *MSD* is affected with the clustering. ANOVA analysis, performed by Minitab release 15 is shown in Table 5.2. It results that the clustering is the significant factor because

P value of this factor is 0.001. Therefore, *MSD* is affected with the clustering within 95% confidence level.

Table 5.2 ANOVA analysis of paddy rice

Source	*d.f.*	*SS*	*MS*	*F*	*P* value
Clustering	4	105.68	26.42	4.90	0.001
Error	170	916.22	5.39	-	-
Total	174	1021.90	-	-	-

Moreover, confidence interval for *MSD* in Table 5.3 can be used to support that fuzzy c-means clustering can be used to reduce the dried product quality variation more than the conventional method. All of confidence intervals for *MSD* from fuzzy c-means clustering are very less than the conventional method.

Table 5.3 Confidence interval for *MSD* of paddy rice

Level	*N*	*MSD*	*SD*	Individual 95% CIs for *MSD* Based on Pooled SD
1	35	3.655	3.167	(-------*------)
2	35	2.160	2.483	(-------*------)
3	35	1.422	1.895	(-------*-------)
4	35	1.723	2.244	(-------*-------)
5	35	1.931	1.459	(------*-------)
Pooled SD = 2.322				1.0 2.0 3.0 4.0

From Figure 5.7, the minimum *MSD* is from clustering with three clusters at 1.422 (% w.b.)^2. Therefore, the optimal number of clustering is three clustering. This can conclude that the raw material should be classified into three clusters in order to minimize the dried product quality variation from the variety of the raw materials.

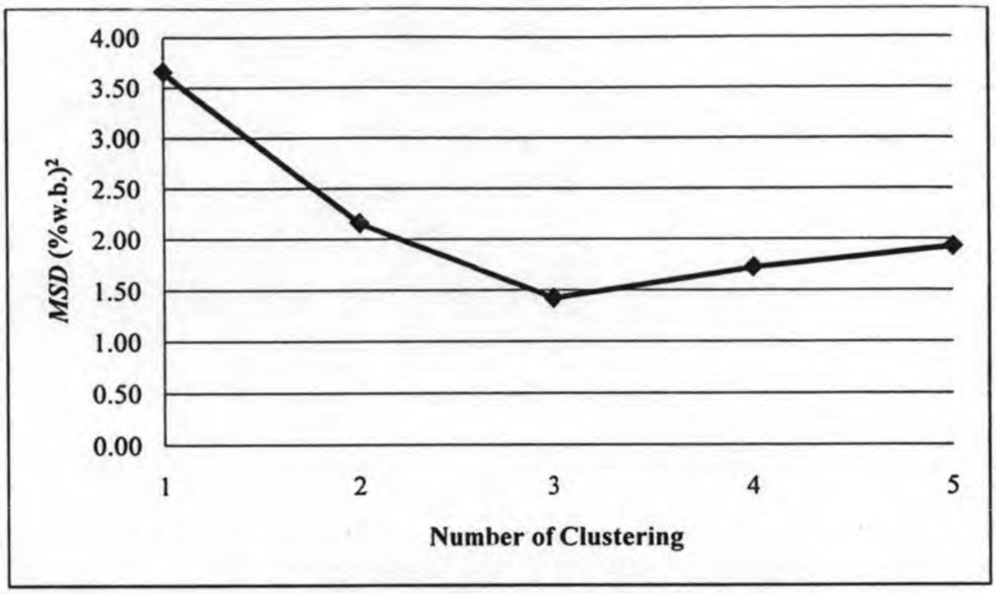

Figure 5.7 *MSD* of drying paddy rice from various number of clustering

5.2 Experimental Results of Cassava Chip

Cassava is a perennial plant widely grown in many tropical countries, including Thailand as one of the most important commercial crops. At present, there are one million hectares devoted to cassava planting in Thailand producing annually 20 million tons of roots. Cassava products are exported mainly to the European Union (EU).

Important product of cassava is dried cassava chip as a source of biological energy in compound animal feeds is increasing rapidly. Thailand is one of the principal exporters. Higher quality standards are possible by an improvement in cassava processing technology. With this importance, drying cassava chip is also a type of dried product studied in this dissertation.

The initial moisture content of cassava chip is in a range of 43-73% w.b. The moisture content after drying is desired to 14.0% w.b. same as paddy rice. From this target, *MSD* of cassava chip after drying can be simplified into the Equation (5.1) same as paddy rice.

5.2.1 Conventional Method

Thirty-five samples of cassava chip are dried with the conventional method. After drying, the product quality variation in term of *MSD* is measured. Its value is 7.691 (% w.b.)^2 greater than zero. It means that there is high quality variation of drying cassava chip. Furthermore, scatterplot between the output and the initial moisture content of drying cassava chip with the conventional method is shown as Figure 5.8. From the Figure 5.8, the drying data scatter widely. This means that the quality of dried cassava chip cannot be controlled by the conventional method.

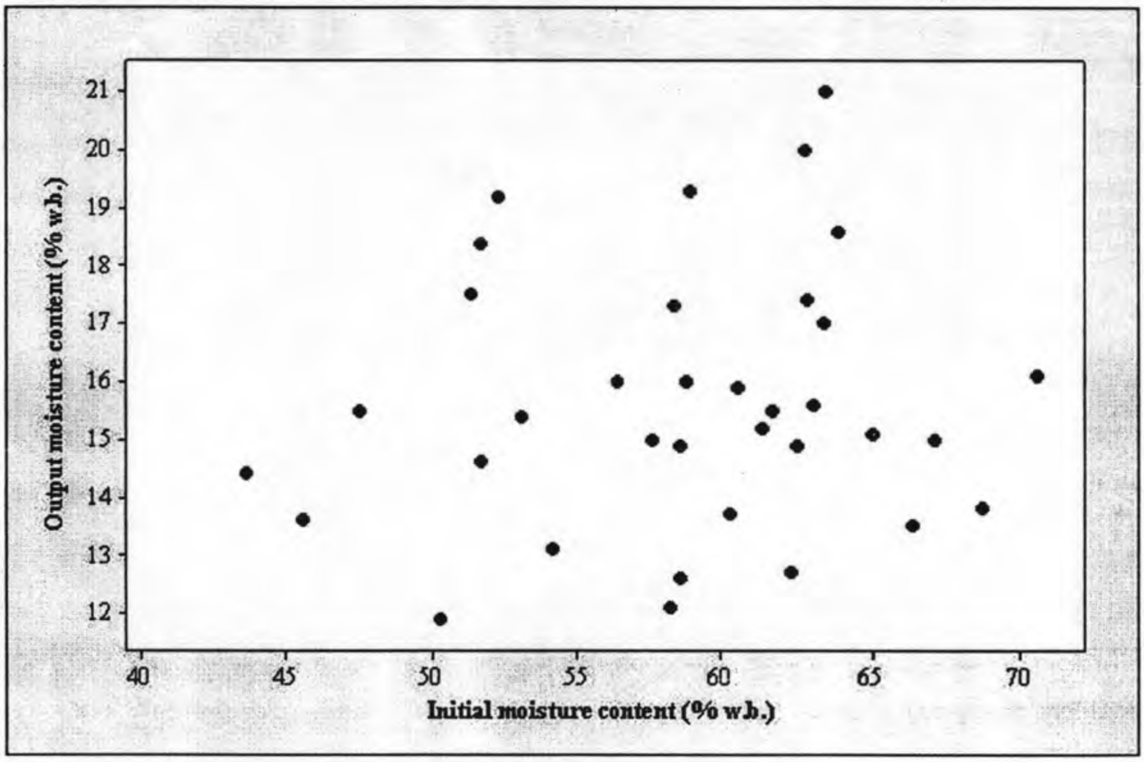

Figure 5.8 Scatterplot of output and initial moisture contents of cassava chip with the conventional method

5.2.2 Fuzzy C-Means Clustering Method

Seventy-five paddy samples from drying historical data are used to cluster by fuzzy c-means clustering. The number of clustering is varied at 2, 3, 4, and 5 clusters. Clustering results from Matlab with *fcm* function are illustrated in Table 5.4.

Table 5.4 Clustering result of cassava chip with the initial moisture content

Clustering	Range of initial moisture content in the i^{th} cluster				
	1	2	3	4	5
2	40.2-58.8	58.9-73.4			
3	40.2-55.5	55.6-62.4	62.5-73.4		
4	40.2-52.9	53.0-60.0	60.1-66.9	67.0-73.4	
5	40.2-52.3	52.4-58.8	58.9-64.0	64.1-69.0	69.1-73.4

The results from the Table 5.4 are used to be criteria for clustering the raw materials into their clusters. After clustering, cassava chips are dried within their clusters and measured *MSD* for evaluating the dried product quality variation. Finally, the optimal number of clustering is selected with the minimum value of *MSD*.

(1) 2 clustering

Thirty-five samples of cassava chip are clustered into two clusters with clustering result from the Table 5.4. Cassava chips in the first cluster are in a range of 40.2-58.8% w.b. (low initial moisture content) and cassava chips in the second cluster are in a range of 58.9-73.4% w.b. (high initial moisture content). After clustering, cassava chips in both clusters are dried within their cluster. Moreover, scatterplot between the output and the initial moisture content of drying cassava chip with the 2 clustering is shown as Figure 5.9.

From the Figure 5.9, the scatterplot of the cluster 1 is almost as equal as the cluster 2. It means that the raw materials within both clusters are not different from each other. However, *MSD* from drying with 2 clustering is 3.313 $(\% \text{ w.b.})^2$.

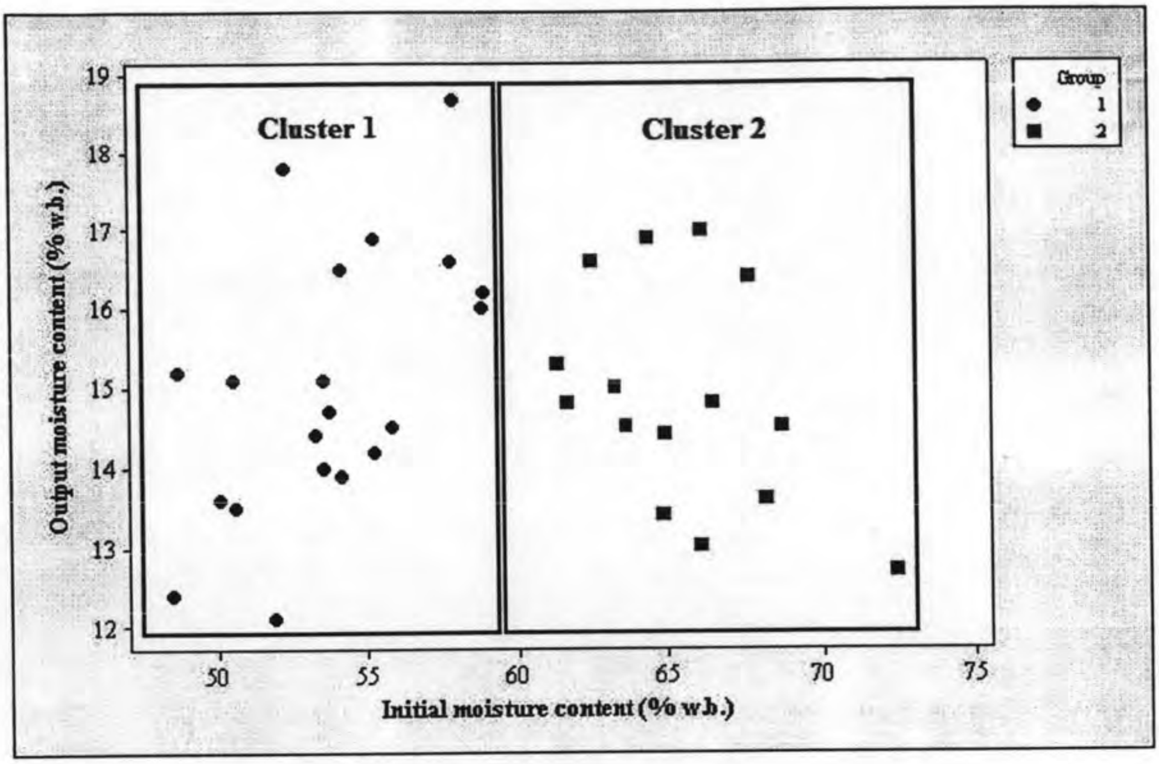

Figure 5.9 Scatterplot of output and initial moisture contents of cassava chip with 2-clustering method

(2) 3 clustering

Thirty-five samples of cassava chip are clustered into three clusters with clustering result from the Table 5.4. Cassava chips in the first cluster are in a range of 40.2-55.5% w.b. (low initial moisture content), cassava chips in the second cluster are in a range of 55.6-62.4% w.b. (medium initial moisture content), and cassava chips in the third cluster are in a range of 62.5-73.4% w.b. (high initial moisture content). After clustering, cassava chips are dried within their clusters. Moreover, scatterplot between the output and the initial moisture content of drying cassava chip with the 3 clustering is shown as Figure 5.10.

From the Figure 5.10, the scatterplot of the cluster 1 and the cluster 3 are wider than the cluster 2. It means that drying within low and high initial moisture contents are more difficult than medium initial moisture content. However, *MSD* from drying with 3 clustering is 2.755 $(\% \text{ w.b.})^2$.

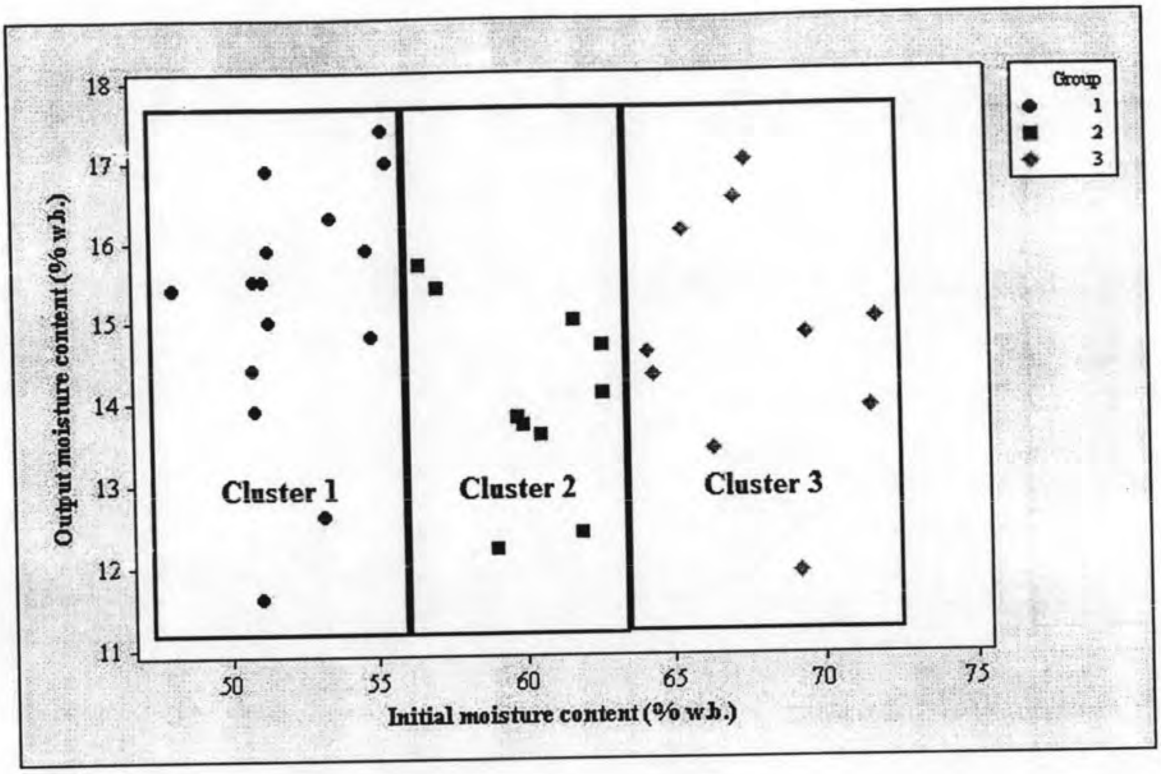

Figure 5.10 Scatterplot of output and initial moisture contents of cassava chip with 3-clustering method

(3) 4 clustering

Thirty-five samples of cassava chip are clustered into four clusters with clustering result from the Table 5.4. Cassava chips in the first cluster are in a range of 40.2-52.9% w.b. (lower initial moisture content), cassava chips in the second cluster are in a range of 53.0-60.0% w.b. (low initial moisture content), cassava chips in the third cluster are in a range of 60.1-66.9% w.b. (medium initial moisture content), and cassava chips in the fourth cluster are in a range of 67.0-73.4% w.b. (high initial moisture content). After clustering, cassava chips are dried within their clusters. Moreover, scatterplot between the output and the initial moisture content of drying cassava chip with the 4 clustering is shown as Figure 5.11.

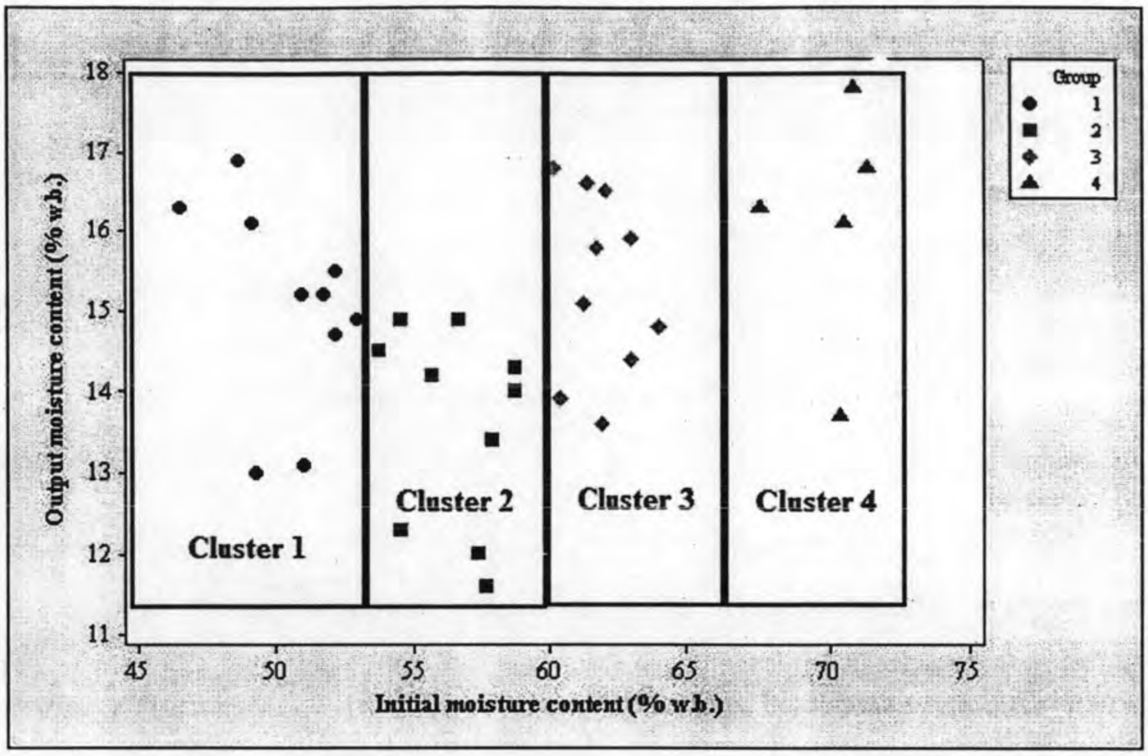

Figure 5.11 Scatterplot of output and initial moisture contents of cassava chip with 4-clustering method

From the Figure 5.11, the scatterplot of the cluster 1 is the widest than other clusters. It means that drying within lower initial moisture content is more difficult to control than other clusters. However, *MSD* from drying with 4 clustering is 2.952 (% w.b.)^2.

(4) 5 clustering

Thirty-five samples of cassava chip are clustered into five clusters with clustering result from the Table 5.4. cassava chips in the first cluster are in a range of 40.2-52.3% w.b. (lower initial moisture content), cassava chips in the second cluster are in a range of 52.4-58.8% w.b. (low initial moisture content), cassava chips in the third cluster are in a range of 58.9-64.0% w.b. (medium initial moisture content), cassava chips in the fourth cluster are in a range of 64.1-69.0% w.b. (high initial moisture content), and cassava chips in the fifth cluster are in a range of 69.1-73.4% w.b. (high initial moisture content). After clustering, cassava chips are dried within their clusters. Moreover, scatterplot between the output and the initial moisture content of drying cassava chip with the 5 clustering is shown as Figure 5.12.

From the Figure 5.12, the scatterplot of the cluster 1 is the widest than other clusters. It means that drying within lower initial moisture content is the most difficult to control than other clusters. However, *MSD* from drying with 5 clustering is 3.694 (% w.b.)^2.

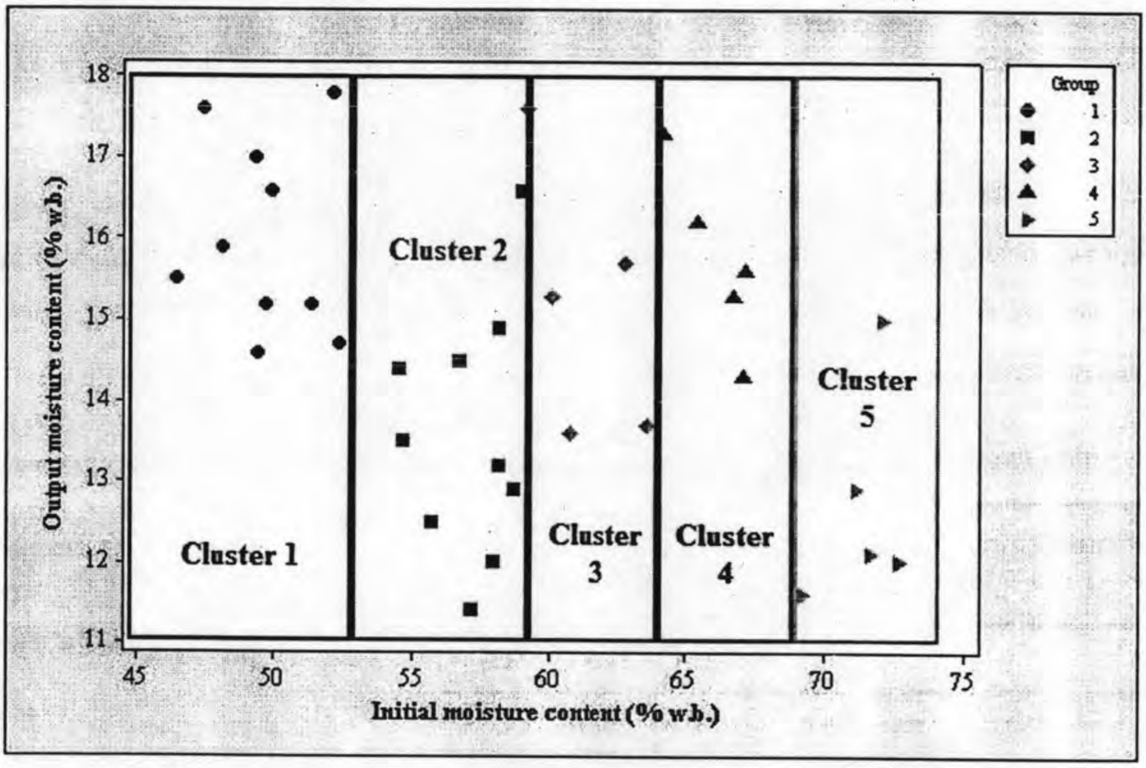

Figure 5.12 Scatterplot of output and initial moisture contents of cassava chip with 5-clustering method

5.2.3 Comparison between Conventional and Fuzzy C-Means Clustering Methods

MSD from drying with the conventional and with fuzzy c-means clustering methods are compared in this section. ANOVA is carried out to ensure that *MSD* is affected with the clustering. ANOVA analysis, performed by Minitab release 15 is shown in Table 5.5. It results that the clustering is the significant factor because

P value of this factor is 0.006. Therefore, *MSD* is affected with the clustering within 95% confidence level.

Table 5.5 ANOVA analysis of cassava chip

Source	*d.f.*	*SS*	*MS*	*F*	*P* value
Clustering	4	588.3	147.1	3.79	0.006
Error	170	6605.3	38.9	-	-
Total	174	7195.5	-	-	-

Moreover, confidence interval for *MSD* in Table 5.6 can be used to support that fuzzy c-means clustering can be used to reduce the dried product quality variation more than the conventional method. All of confidence intervals for *MSD* from fuzzy c-means clustering are very less than the conventional method.

Table 5.6 Confidence interval for *MSD* of cassava chip

Level	*N*	*MSD*	*SD*	Individual 95% CIs for *MSD* Based on Pooled SD ---+-----|-----+-----|-.
1	35	7.691	11.612	(--------*-------)
2	35	3.313	4.764	(-------*---------)
3	35	2.755	3.055	(-------*-------)
4	35	2.952	3.313	(--------*--------)
5	35	3.694	4.054	(--------*--------)
Pooled SD = 6.233				---+-----|-----+-----|-. 2.5 5.0 7.5 10.0

From Figure 5.13, the minimum *MSD* is from clustering with three clusters at 2.755 (% w.b.)^2. Therefore, the optimal number of clustering is three clustering. This can conclude that the raw material should be classified into three clusters in order to minimize the dried product quality variation from the variety of the raw materials.

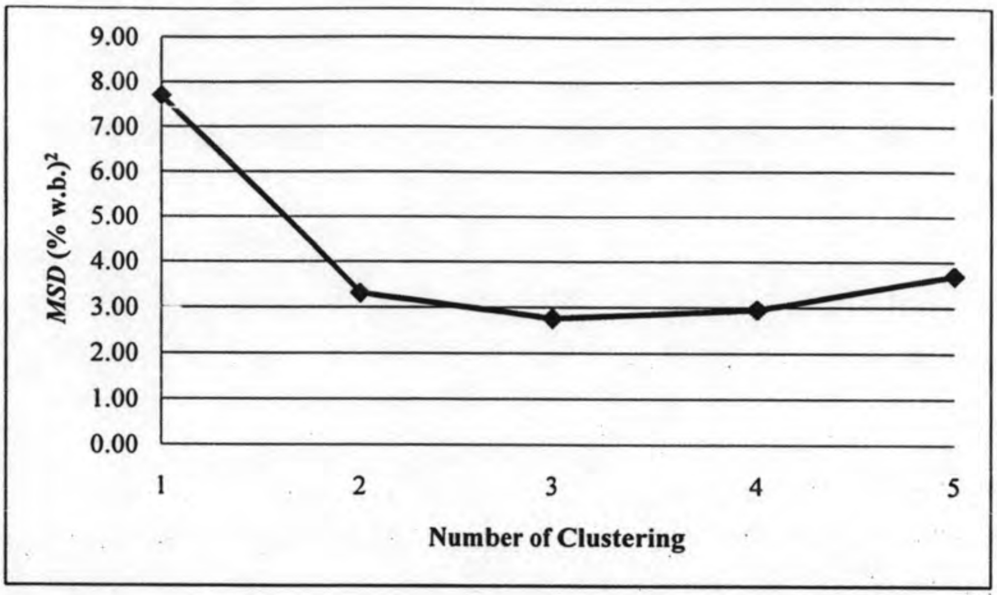

Figure 5.13 *MSD* of drying cassava chip from various number of clustering

5.3 Experimental Results of Tobacco

Tobacco is an agricultural product processed from the fresh leaves of plants in the geus *Nicotina*. It can be consumed, used as an organic pesticide, and in the form of nicotine titrate in some medicines (Eric, 2007). Although it is harmful to health of human, it is one of most important commercial products for Thai agro-industry.

The initial moisture content of tobacco is in a range of 15-22% w.b. The moisture content after drying is desired to 12.5% w.b. From this target, *MSD* of tobacco after drying can be simplified into the Equation (5.2).

$$MSD = \frac{1}{n}\sum_{i=1}^{n}(y_i - 12.5)^2 \qquad (5.2)$$

where

y_i = the measured moisture content of tobacco after drying

n = the numbers of sample size

5.3.1 Conventional Method

Thirty-five samples of tobacco are dried with the conventional method. After drying, the product quality variation in term of *MSD* is measured. Its value is 2.902 (% w.b.)^2 greater than zero. It means that there is high quality variation of drying tobacco. Furthermore, scatterplot between the output and the initial moisture content of drying tobacco with the conventional method is shown as Figure 5.14. From the Figure 5.14, the drying data scatter widely. This means that the quality of dried tobacco cannot be controlled by the conventional method.

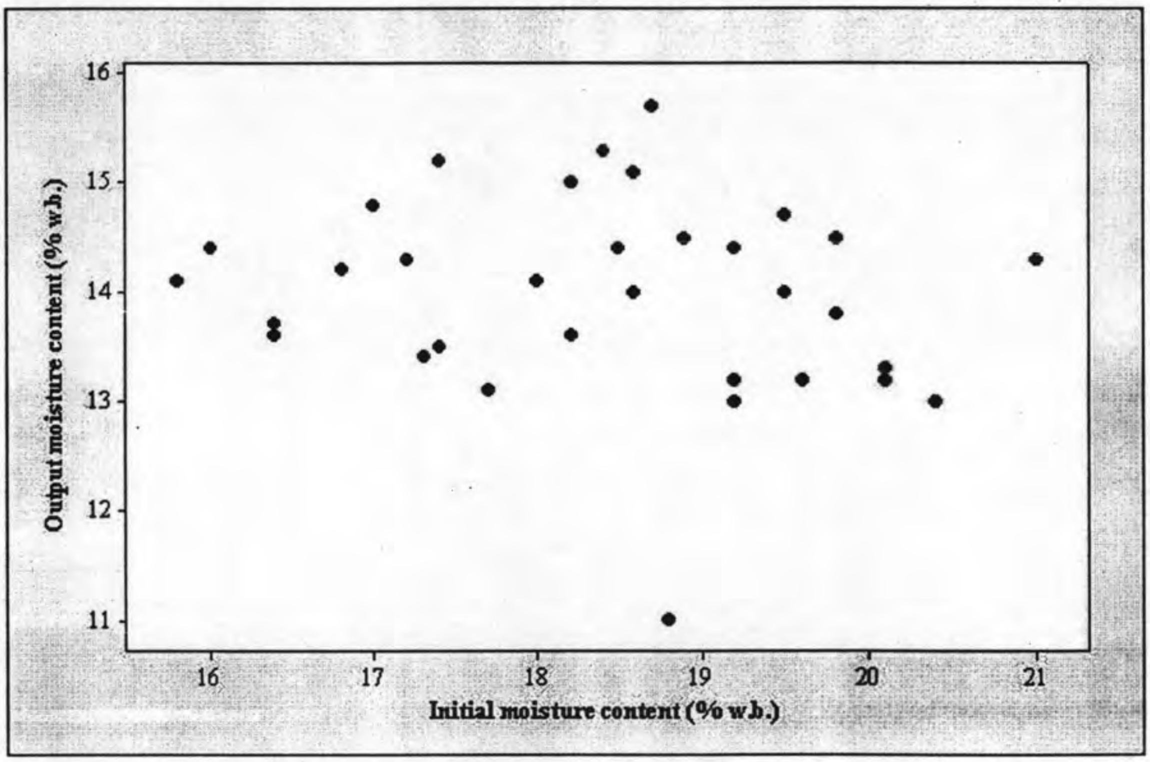

Figure 5.14 Scatterplot of output and initial moisture contents of tobacco with the conventional method

5.3.2 Fuzzy C-Means Clustering Method

Seventy-five paddy samples from drying historical data are used to cluster by fuzzy c-means clustering. The number of clustering is varied at 2, 3, 4, and 5 clusters. Clustering results from Matlab with *fcm* function are illustrated in Table 5.7.

Table 5.7 Clustering result of tobacco with the initial moisture content

Clustering	Range of initial moisture content in the i^{th} cluster				
	1	**2**	**3**	**4**	**5**
2	15.0-18.9	19.0-22.4	-	-	-
3	15.0-17.6	17.7-19.4	19.5-22.4	-	-
4	15.0-17.4	17.5-18.4	18.5-19.8	19.9-22.4	-
5	15.0-17.3	17.4-18.1	18.2-18.9	19.0-19.9	20.0-22.4

The results from the Table 5.7 are used to be criteria for clustering the raw materials into their clusters. After clustering, tobacco is dried within their clusters and measured *MSD* for evaluating the dried product quality variation. Finally, the optimal number of clustering is selected with the minimum value of *MSD*.

(1) 2 clustering

Thirty-five samples of tobacco are clustered into two clusters with clustering result from the Table 5.7. Tobacco in the first cluster is in a range of 15.0-18.9% w.b. (low initial moisture content) and tobacco in the second cluster is in a range of 19.0-22.4% w.b. (high initial moisture content). After clustering, tobacco in both clusters is dried within its cluster. Moreover, scatterplot between the output and the initial moisture content of drying tobacco with the 2 clustering is shown as Figure 5.15.

From the Figure 5.15, the scatterplot of the cluster 1 is almost as equal as the cluster 2. It means that drying tobacco within both clusters is not different from each other. However, *MSD* from drying with 2 clustering is 1.595 (% w.b.)^2.

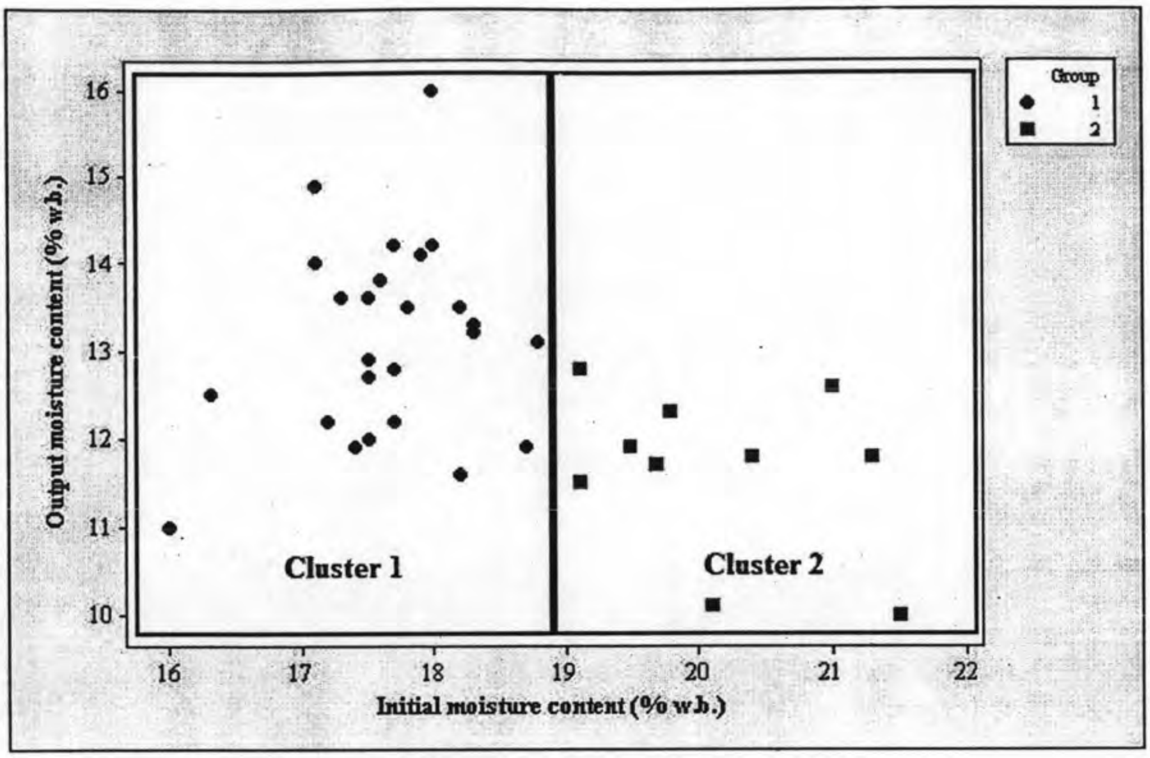

Figure 5.15 Scatterplot of output and initial moisture contents of tobacco with 2-clustering method

(2) 3 clustering

Thirty-five samples of tobacco are clustered into three clusters with clustering result from the Table 5.7. Tobacco in the first cluster is in a range of 15.0-17.6% w.b. (low initial moisture content), tobacco in the second cluster is in a range of 17.7-19.4% w.b. (medium initial moisture content), and tobacco in the third cluster is in a range of 19.5-22.4% w.b. (high initial moisture content). After clustering, tobacco is dried within its cluster. Moreover, scatterplot between the output and the initial moisture content of drying tobacco with the 3 clustering is shown as Figure 5.16.

From the Figure 5.16, the scatterplot of the cluster 3 is the widest than other clusters. It means that drying tobacco within high initial moisture content is more difficult than other ranges. However, *MSD* from drying with 3 clustering is 0.805 (% w.b.)^2.

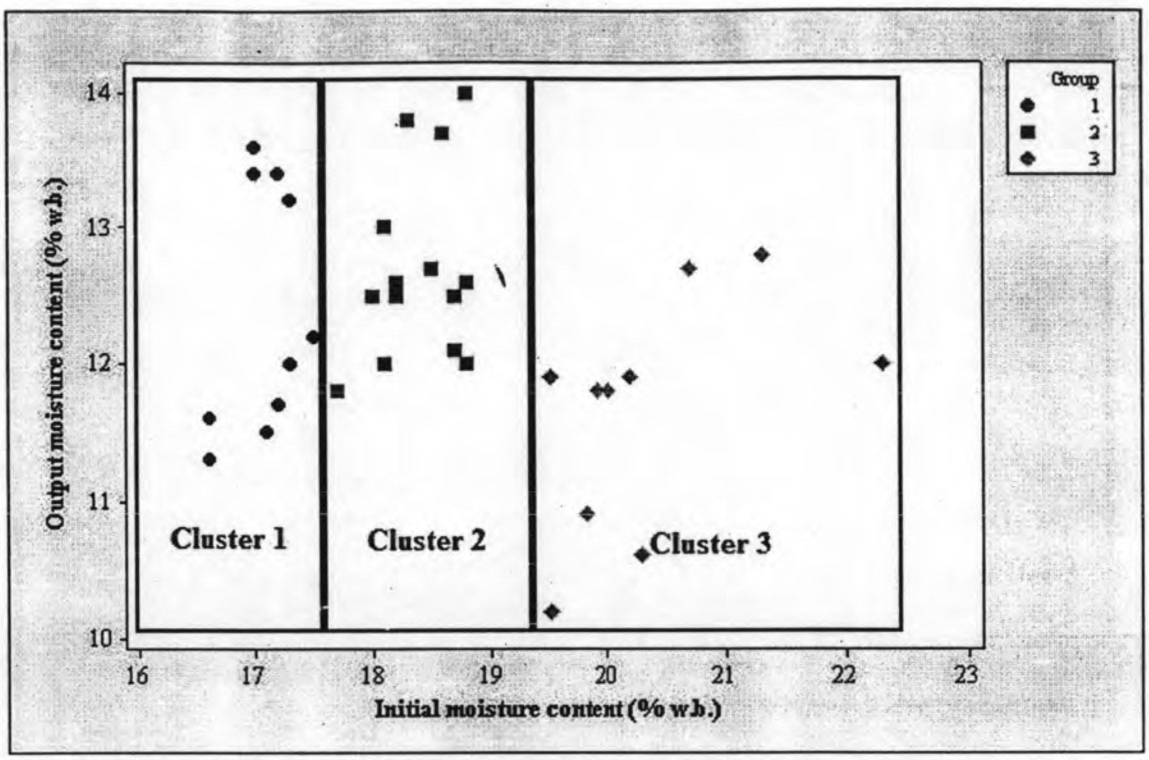

Figure 5.16 Scatterplot of output and initial moisture contents of tobacco with 3-clustering method

(3) **4 clustering**

Thirty-five samples of tobacco are clustered into four clusters with clustering result from the Table 5.7. Tobacco in the first cluster is in a range of 15.0-17.4% w.b. (lower initial moisture content), tobacco in the second cluster is in a range of 17.5-18.4% w.b. (low initial moisture content), tobacco in the third cluster is in a range of 18.5-19.8% w.b. (medium initial moisture content), and tobacco in the fourth cluster is in a range of 19.9-22.4% w.b. (high initial moisture content). After clustering, tobacco is dried within its cluster. Moreover, scatterplot between the output and the initial moisture content of drying tobacco with the 4 clustering is shown as Figure 5.17.

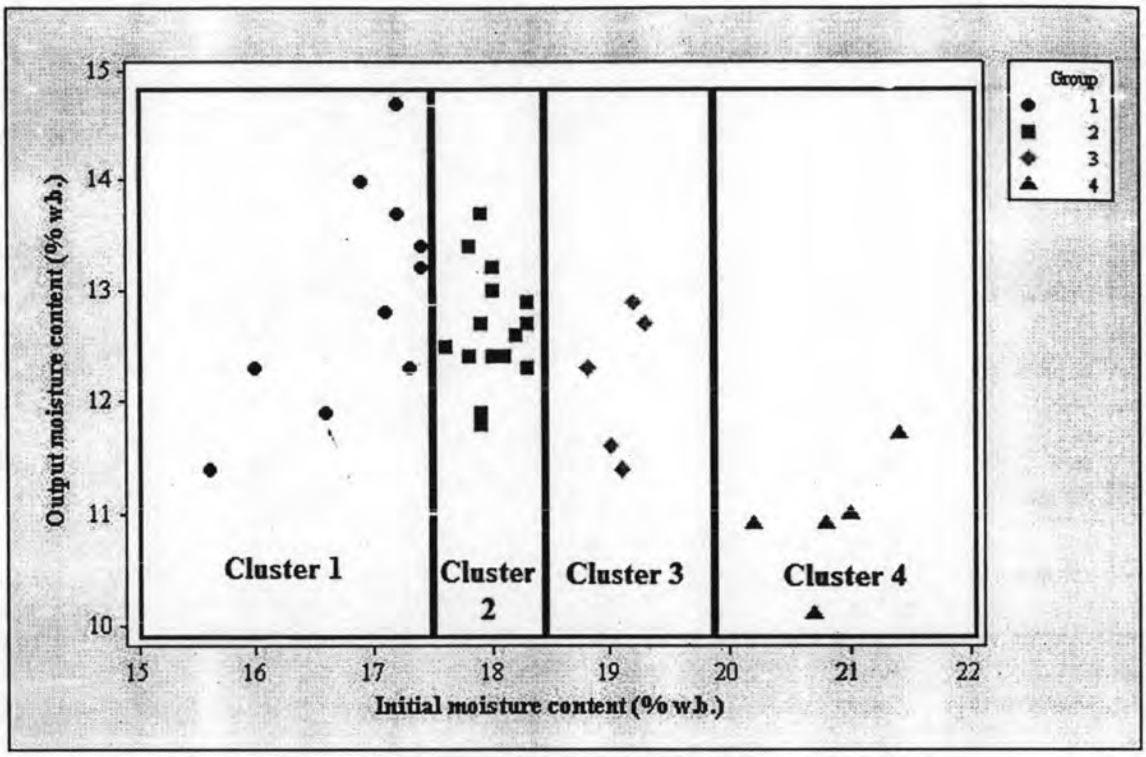

Figure 5.17 Scatterplot of output and initial moisture contents of tobacco with 4-clustering method

From the Figure 5.17, the scatterplots of the cluster 1 and the cluster 4 are wider than other clusters. It means that drying within lower and high initial moisture contents are more difficult to control than other clusters. However, *MSD* from drying with 4 clustering is 0.907 (% w.b.)^2.

(4) 5 clustering

Thirty-five samples of tobacco are clustered into five clusters with clustering result from the Table 5.7. Tobacco in the first cluster is in a range of 15.0-17.3% w.b. (lower initial moisture content), tobacco in the second cluster is in a range of 17.4-18.1% w.b. (low initial moisture content), tobacco in the third cluster is in a range of 18.2-18.9% w.b. (medium initial moisture content), tobacco in the fourth cluster is in a range of 19.0-19.9% w.b. (high initial moisture content), and tobacco in the fifth cluster is in a range of 20.0-22.4% w.b. (high initial moisture content). After clustering, tobacco is dried within its cluster. Moreover, scatterplot between the output and the initial moisture content of drying longan with the 5 clustering is shown as Figure 5.18.

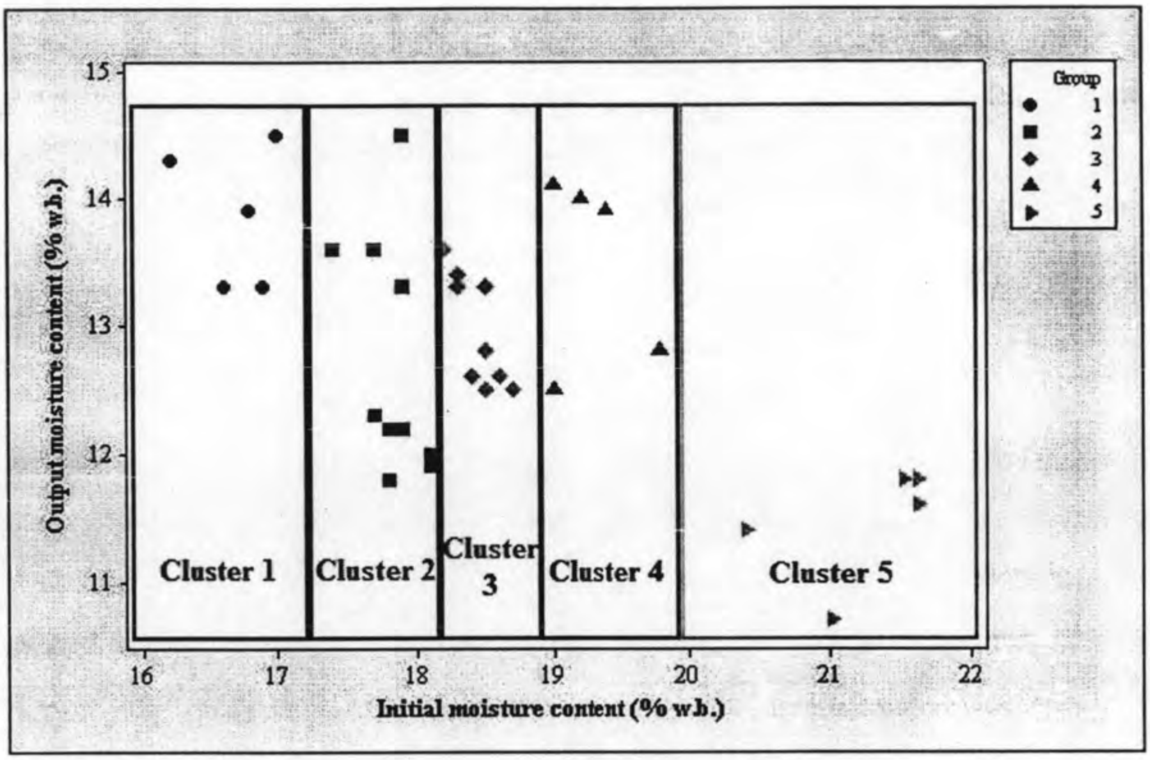

Figure 5.18 Scatterplot of output and initial moisture contents of tobacco with 5-clustering method

From the Figure 5.18, the scatterplot of the cluster 5 is the widest than other clusters. It means that drying within higher initial moisture content is the most difficult to control than other clusters. However, *MSD* from drying with 5 clustering is 1.029 (% w.b.)^2.

5.3.3 Comparison between Conventional and Fuzzy C-Means Clustering Methods

MSD from drying with the conventional and with fuzzy c-means clustering methods are compared in this section. ANOVA is carried out to ensure that *MSD* is affected with the clustering. ANOVA analysis, performed by Minitab release 15 is shown in Table 5.8. It results that the clustering is the significant factor because

P value of this factor is 0.000. Therefore, *MSD* is really affected with the clustering within 95% confidence level.

Table 5.8 ANOVA analysis of tobacco

Source	*d.f.*	*SS*	*MS*	*F*	*P* value
Clustering	4	105.56	26.39	7.92	0.000
Error	170	566.37	3.33	-	-
Total	174	671.93	-	-	-

Moreover, confidence interval for *MSD* in Table 5.9 can be used to support that fuzzy c-means clustering can be used to reduce the dried product quality variation more than the conventional method. All of confidence intervals for *MSD* from fuzzy c-means clustering are very less than the conventional method. Moreover, In 3, 4, and 5 clustering are not quite different from each other.

Table 5.9 Confidence interval for *MSD* of tobacco

Level	*N*	*MSD*	*SD*	Individual 95% CIs for *MSD* Based on Pooled SD ----|-----+-----|-----+
1	35	2.902	2.450	(-----*-----)
2	35	1.595	2.494	(-----*-----)
3	35	0.805	1.310	(-----*-----)
4	35	0.907	1.346	(-----*-----)
5	35	1.029	1.161	(-----*-----)
Pooled SD = 1.825				----|-----+-----|-----+ 1.0 2.0 3.0 4.0

From Figure 5.19, the minimum *MSD* is from clustering with three clusters at 0.805 (% w.b.)^2. Therefore, the optimal number of clustering is three clustering. This can conclude that the raw material should be classified into three clusters in order to minimize the dried product quality variation from the variety of the raw materials.

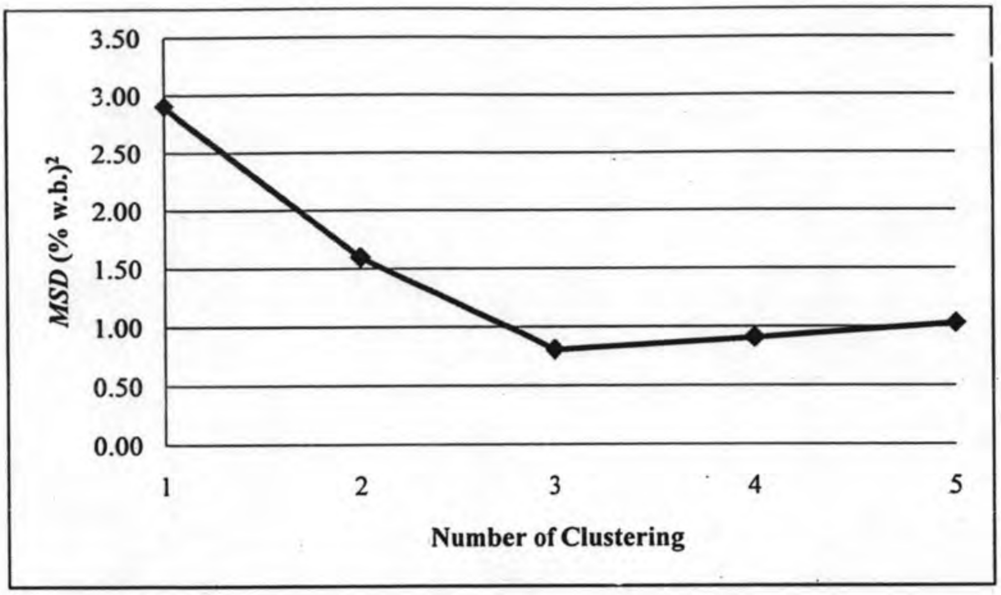

Figure 5.19 *MSD* of drying tobacco from various number of clustering

5.4 Experimental Results of Longan

Longan is an important commercial fruit in the Northern Thailand. One of the problems challenging longan for longan grower is that the fresh product in season are overwhelming (Adchariyaviriya, et al., 2001). The common practice is to dry whole longan into the dried product. However, there is still a problem that longan cannot be dried to the target.

For this dissertation, the initial moisture content of longan is in a range of 85-97% w.b. The moisture content after drying is desired to 18.0% w.b. From this target, *MSD* of longan after drying can be simplified into the Equation (5.3).

$$MSD = \frac{1}{n}\sum_{i=1}^{n}(y_i - 18)^2 \qquad (5.3)$$

where

y_i = the measured moisture content of longan after drying

n = the numbers of sample size

5.4.1 Conventional Method

Thirty-five samples of longan are dried with the conventional method. After drying, the product quality variation in term of *MSD* is measured. Its value is 10.758 (% w.b.)^2 greater than zero. It means that there is high quality variation of drying longan. Furthermore, scatterplot between the output and the initial moisture content of drying longan with the conventional method is shown as Figure 5.20. From the Figure 5.20, the drying data scatter widely. This means that the quality of dried longan cannot be controlled by the conventional method.

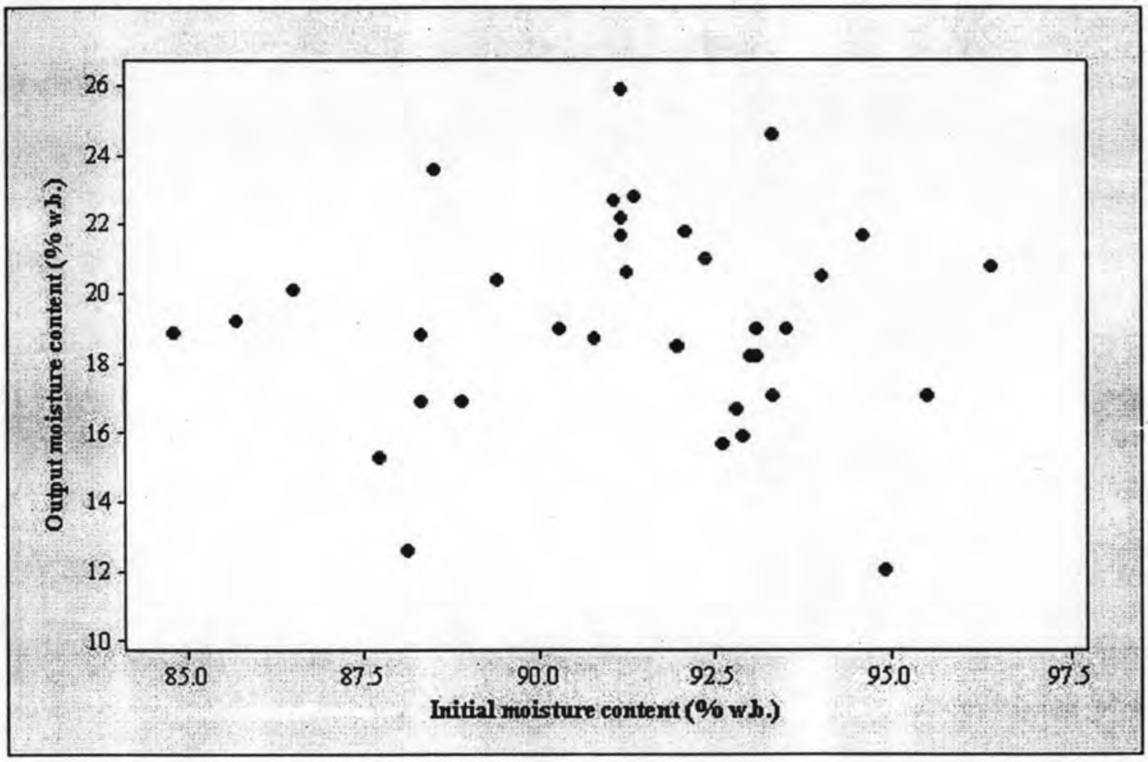

Figure 5.20 Scatterplot of output and initial moisture contents of longan with the conventional method

5.4.2 Fuzzy C-Means Clustering Method

Seventy-five paddy samples from drying historical data are used to cluster by fuzzy c-means clustering. The number of clustering is varied at 2, 3, 4, and 5 clusters. Clustering results from Matlab with *fcm* function are illustrated in Table 5.10.

Table 5.10 Clustering result of longan with the initial moisture content

Clustering	Range of initial moisture content in the i^{th} cluster				
	1	2	3	4	5
2	84.6-92.0	92.1-97.0			
3	84.6-89.5	89.6-93.0	93.1-97.0		
4	84.6-87.2	87.3-89.9	90.0-93.0	93.1-97.0	
5	84.6-87.1	87.2-89.5	89.6-93.0	93.1-94.9	95.0-97.0

The results from the Table 5.10 are used to be criteria for clustering the raw materials into their clusters. After clustering, longan is dried within their clusters and measured *MSD* for evaluating the dried product quality variation. Finally, the optimal number of clustering is selected with the minimum value of *MSD*.

(1) 2 clustering

Thirty-five samples of longan are clustered into two clusters with clustering result from the Table 5.10. Longan in the first cluster is in a range of 84.6-92.0% w.b. (low initial moisture content) and longan in the second cluster is in a range of 92.1-97.0% w.b. (high initial moisture content). After clustering, longan in both clusters is dried within its cluster. Moreover, scatterplot between the output and the initial moisture content of drying longan with the 2 clustering is shown as Figure 5.21.

From the Figure 5.21, the scatterplot of the cluster 1 is wider than the cluster 2. It means that drying longan within low initial moisture content is more difficult to control than within high initial moisture content.However, *MSD* from drying longan with 2 clustering is 4.452 (% w.b.)^2.

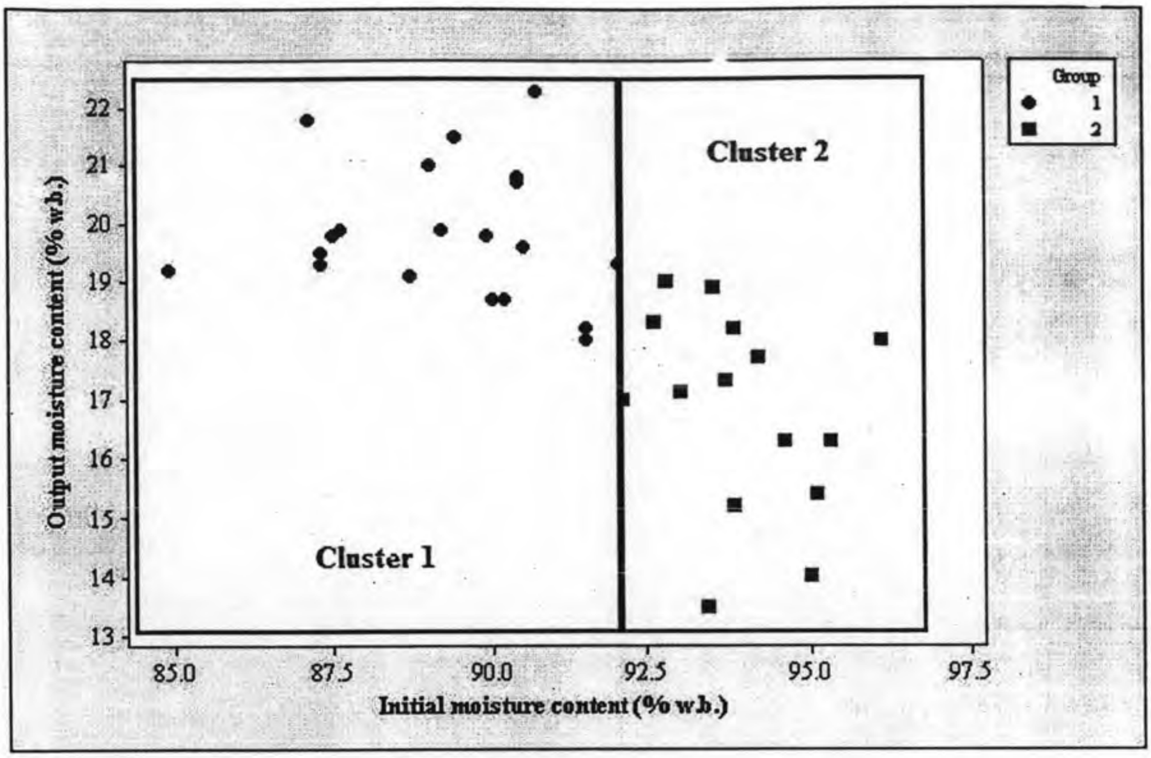

Figure 5.21 Scatterplot of output and initial moisture contents of longan with 2-clustering method

(2) 3 clustering

Thirty-five samples of longan are clustered into three clusters with clustering result from the Table 5.10. Longan in the first cluster is in a range of 84.6-89.5% w.b. (low initial moisture content), longan in the second cluster is in a range of 89.6-93.0% w.b. (medium initial moisture content), and longan in the third cluster is in a range of 93.1-97.0% w.b. (high initial moisture content). After clustering, longan is dried within its cluster. Moreover, scatterplot between the output and the initial moisture content of drying longan with the 3 clustering is shown as Figure 5.22.

From the Figure 5.22, the scatterplots of the cluster 1 and the cluster 3 are wider than the cluste 2. It means that drying longan within low and high initial moisture contents are more difficult than medium initial moisture content. However, *MSD* from drying with 3 clustering is 2.776 (% w.b.)^2.

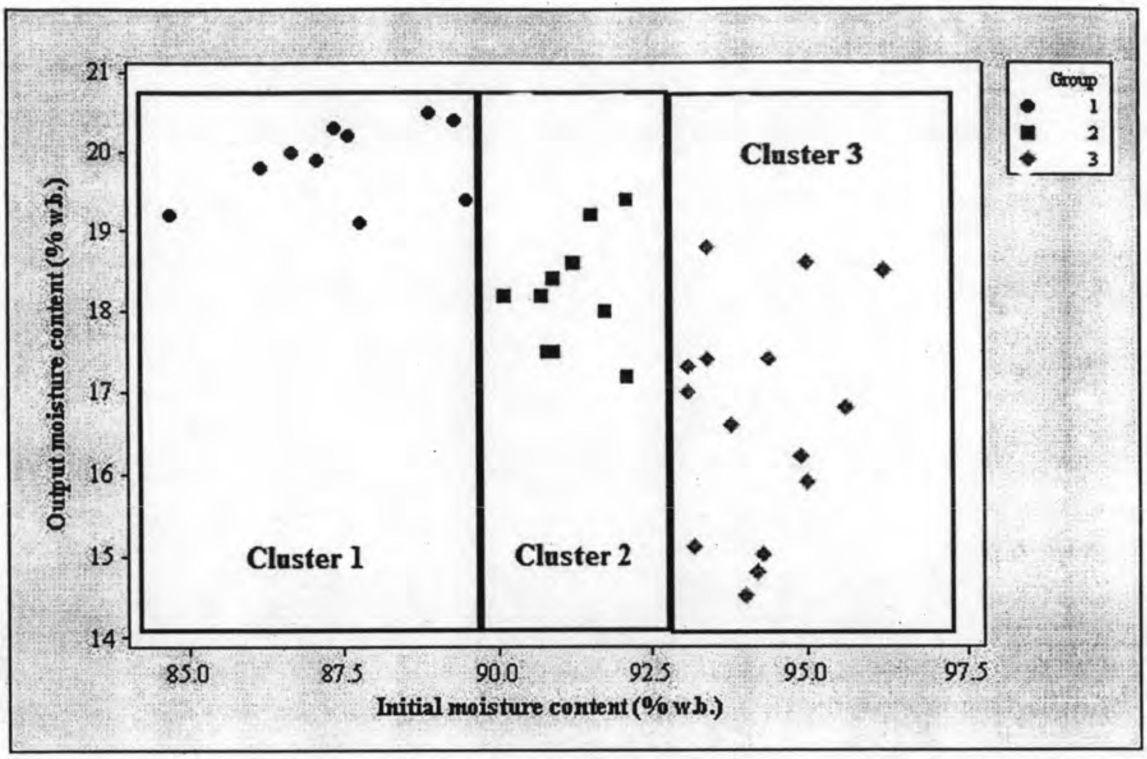

Figure 5.22 Scatterplot of output and initial moisture contents of longan with 3-clustering method

(3) 4 clustering

Thirty-five samples of longan are clustered into four clusters with clustering result from the Table 5.10. Longan in the first cluster is in a range of 84.6-87.2% w.b. (lower initial moisture content), longan in the second cluster is in a range of 87.3-89.9% w.b. (low initial moisture content), longan in the third cluster is in a range of 90.0-93.0% w.b. (medium initial moisture content), and longan in the fourth cluster is in a range of 93.1-97.0% w.b. (high initial moisture content). After clustering, longan is dried within its cluster. Moreover, scatterplot between the output and the initial moisture content of drying longan with the 4 clustering is shown as Figure 5.23.

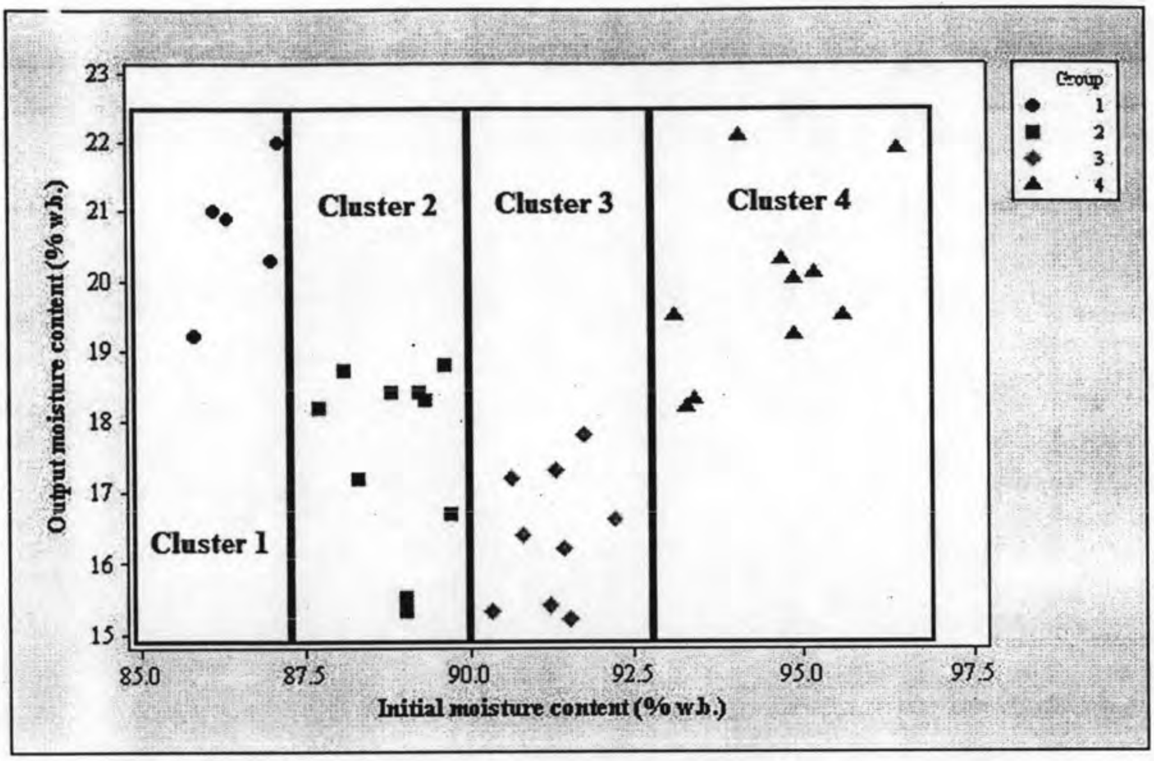

Figure 5.23 Scatterplot of output and initial moisture contents of longan with 4-clustering method

From the Figure 5.23, the scatterplots of the cluster 4 is the widest than other clusters. It means that drying within high initial moisture contents is the most difficult to control than other clusters. However, *MSD* from drying with 4 clustering is 4.199 (% w.b.)^2.

(4) 5 clustering

Thirty-five samples of longan are clustered into five clusters with clustering result from the Table 5.10. Longan in the first cluster is in a range of 84.6-87.1% w.b. (lower initial moisture content), longan in the second cluster is in a range of 87.2-89.5% w.b. (low initial moisture content), longan in the third cluster is in a range of 89.6-93.0% w.b. (medium initial moisture content), longan in the fourth cluster is in a range of 93.1-94.9% w.b. (high initial moisture content), and longan in the fifth cluster is in a range of 95.0-97.0% w.b. (high initial moisture content). After clustering, longan is dried within its cluster. Moreover, scatterplot between the output and the initial moisture content of drying longan with the 5 clustering is shown as Figure 5.24.

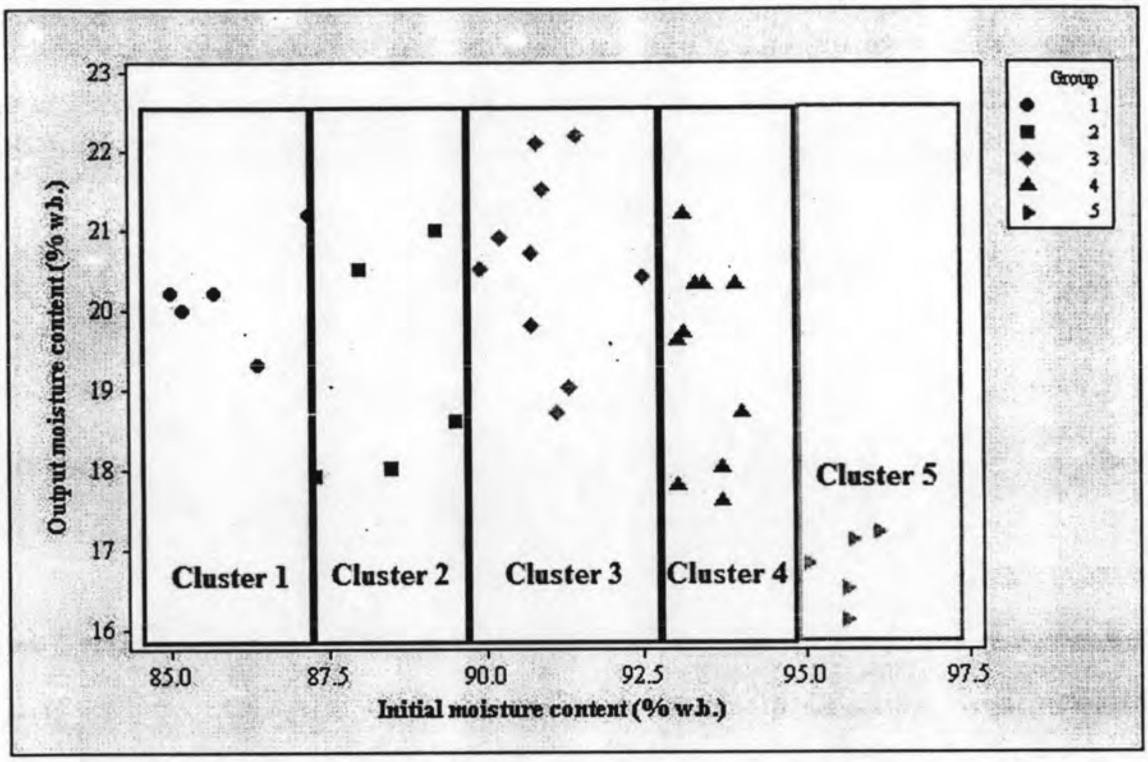

Figure 5.24 Scatterplot of output and initial moisture contents of longan with 5-clustering method

From the Figure 5.24, the scatterplot of the cluster 3 is the widest than other clusters. It means that drying within medium initial moisture content is the most difficult to control than other clusters. However, *MSD* from drying with 5 clustering is 4.611 (% w.b.)^2.

5.4.3 Comparison between Conventional and Fuzzy C-Means Clustering Methods

MSD from drying with the conventional and with fuzzy c-means clustering methods are compared in this section. ANOVA is carried out to ensure that *MSD* is affected with the clustering. ANOVA analysis, performed by Minitab release 15 is shown in Table 5.11. It results that the clustering is the significant factor because

P value of this factor is 0.000. Therefore, *MSD* is really affected with the clustering within 95% confidence level.

Table 5.11 ANOVA analysis of longan

Source	*d.f.*	*SS*	*MS*	*F*	*P* value
Clustering	4	1349.3	337.3	5.70	0.000
Error	170	10052.7	59.1	-	-
Total	174	11402.0	-	-	-

Moreover, confidence interval for *MSD* in Table 5.12 can be used to support that fuzzy c-means clustering can be used to reduce the dried product quality variation more than the conventional method. All of confidence intervals for *MSD* from fuzzy c-means clustering are very less than the conventional method. Moreover, In 3, 4, and 5 clustering are not quite different from each other.

Table 5.12 Confidence interval for *MSD* of tobacco

Level	*N*	*MSD*	*SD*	Individual 95% CIs for *MSD* Based on Pooled SD
1	35	10.758	14.531	(------- * -------)
2	35	4.452	5.595	(------- * -------)
3	35	2.776	3.218	(------- * ------)
4	35	4.199	4.646	(------ * -------)
5	35	4.611	4.613	(------ * -------)
Pooled SD = 7.690				3.5 7.0 10.5 14.0

From Figure 5.25, the minimum *MSD* is from clustering with three clusters at 2.776 (% w.b.)^2. Therefore, the optimal number of clustering is three clustering. This can conclude that the raw material should be classified into three clusters in order to minimize the dried product quality variation from the variety of the raw materials.

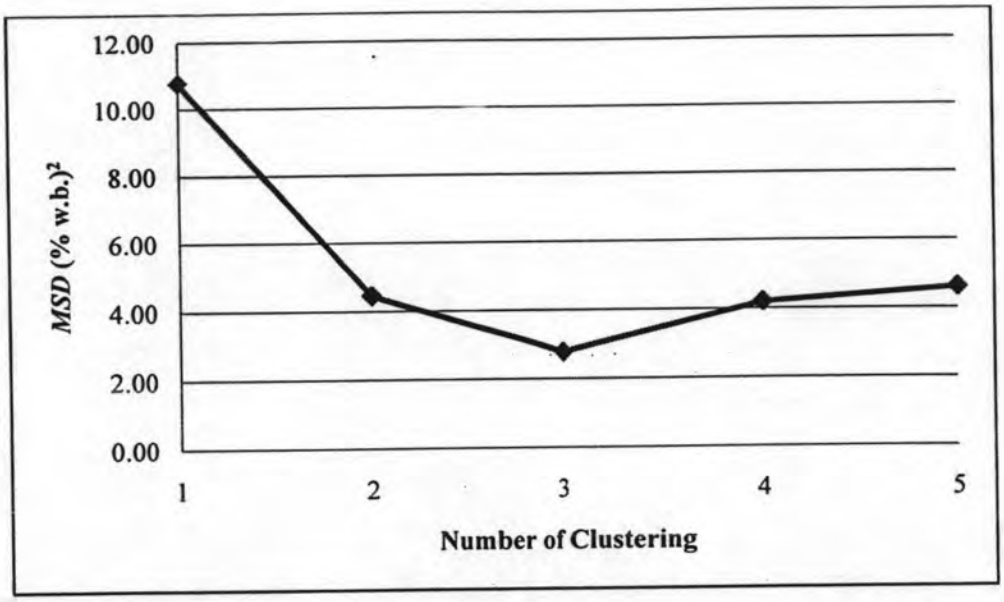

Figure 5.25 *MSD* of drying longan from various number of clustering

5.5 Conclusion

The aim of this chapter is to manage the variety of the raw material in order to minimize the dried product quality variation. Fuzzy c-means clustering is a method selected to manage the variety of the raw material by organizing the similarities of the raw materials into their clusters. The number of clustering is varied at 2, 3, 4, and 5 clustering. After clustering, the raw materials are dried within their clusters and then *MSD* for each clustering is measured to evaluate the dried product quality variation. Finally, the optimal number is determined to establish the ranges for organizing the raw materials.

From all of four dried products, three clustering is the optimal number of clustering for every type of the dried products. Firstly, *MSD* from drying paddy rice can be reduced from 3.655 to 1.422 (% w.b.)^2. Secondly, *MSD* from cassava chip drying can be reduced from 7.691 to 2.755 (% w.b.)^2. Thirdly, *MSD* from tobacco drying can be reduced from 2.902 to 0.805 (% w.b.)^2. Finally, *MSD* from longan drying can be reduced from 10.758 to 2.776 (% w.b.)^2.

To investigate why three clustering is the optimal number of clustering for every product type, interview of operators controlling the drying process is used in this dissertation. From the interview, it results that drying with more than three clustering is very difficult to control and adjust drying temperature levels. For example of drying with four and five clustering, each range of the initial moisture content is very narrow and closed. This narrow and closed range is a cause that a little temperature adjustment extremely affects the output moisture content. Moreover, drying with less than two clustering is very difficult to adjust drying temperature levels because each cluster is so wide range that drying temperature levels are more frequently adjusted. Thus, organizing the raw material into three clustering is the optimal number of clustering that can minimize the dried product quality variation. The range of the initial moisture content with three clustering can be summarized in Table 5.13.

Table 5.13 Summary of the range of the initial moisture content of three clustering

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