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Study on Cleaning of Post-Harvest Bananas on the Basis of Food Safety

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Abstract: Banana was recognized as the fourth largest food crop by the United Nations Food and Agriculture Organization (FAO) for its extensive cultivation and rich nutrients. Food safety problems regarding banana has been a common concern of all mankind. In this paper, the necessity of cleaning bananas was discussed first, the possibility of cleaning bananas with pure water was studied on such a basis and the cleaning process with pure water was optimized then. To produce samples with maximum cleanliness, the parameters for cleaning bananas such as nozzle shape, spray angle, spray height, conveying speed and nozzle arrangement were elaborately selected. As a statistical design of experimental technique, the Taguchi method was used to optimize the selected parameters. The results were analyzed with SPSS software by adopting analyses of variance (ANOVA) and the signal-to-noise (S/N) ratios for optimal parameters and a model was established thereon. Researches show that cleaning plays a crucial role in preservation of bananas. Quality of cleaned bananas is evidently higher than uncleaned bananas preserved in the same period in terms of flesh firmness and peel color. Nozzle shape among the processing parameters has the most significant influence on cleanliness. The established model reveals a squared relationship among power of nozzle shape, spray angle, spray height, conveying speed and nozzle arrangement. From the experiments, sample with over 95% of cleanliness was obtained.

Key words: Food safety · Cleaning bananas · Taguchi method · Cleanliness model

INTRODUCTION

Banana is a plant in the genus *Musa* under the family Musaceae. Banana is rich in saccharides and carbohydrates with high nutritive value, as the most distinctive fruit in tropical and subtropical regions [1]. According to statistics, there are around 136 countries and regions growing bananas, the majority of which are developing countries, including India, China, Philippines, Brazil, Ecuador and Indonesia [2]. The output of bananas in the above six countries represents 60-70% of yield of bananas in the world [3]. Bananas are used in place of food in some countries suffering from food shortage [4]. Banana is even recognized by the United Nations Food and Agriculture Organization as the fourth largest food crop ranking after rice, wheat and corn [5]. Therefore, it is a fundamental issue for the study on bananas seeking for high-efficient post-harvest treatment and high-standard food safety to ensure that bananas ready for eating are not toxic and do not cause any acute, sub-acute or chronic hazards to human health, so as to solve food shortage in developing countries and protect the health of people in developing countries.

The post-harvest treatment processes of bananas include picking, cleaning, grading, weighing, fresh-keeping, packaging, cold storage and transportation and so on [6]. Among these post-harvest treatment processes, cleaning has the greatest impact on food safety of bananas. Immersion cleaning is used in most banana-producing countries (Fig. 1), pursuant to which, bananas are soaked in aqueous solution containing chemical fungicides such as iprodione [7], imazalil [8], potassium permanganate [9], acetic acid [10], alum [11] and other substances for the initial cleaning and then immersed in bleaching solution for the secondary cleaning. With two rounds of cleaning, dirt on banana peel is cleared, but it has residual chemical fungicides on the peel. The entire post-harvest treatment process does nothing to remove

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Fig. 1: Immersion cleaning a. Initial cleaning, b. Secondary cleaning

the residual chemical fungicides, resulting in potential safety hazards. Meanwhile, it causes huge environmental pollution as chemical solution directly discharges outdoors after repeatedly used for cleaning bananas [11].

Accordingly, problems such as how to ensure food safety of bananas, to avoid harm to people's health caused by chemicals used in cleaning and sterilizing, to reduce environmental pollution generated from discharge of chemical reagent and to develop a high-efficient and low-cost method to clean bananas, have become urgent issues nowadays, however, there is few report relating to research on cleaning bananas.

The method of cleaning bananas was studied on the basis of food safety in this paper. Specifically, the impact of cleaning on storage life of bananas was analyzed, the necessity of cleaning bananas was discussed, the spraying system with recoverable pure water for cleaning bananas was designed, the Taguchi method for cleaning bananas with pure water was designed on account of nozzle shape, spray angle, spray height, conveying speed and nozzle arrangement. and the process of cleaning bananas with pure water was researched and developed.

MATERIALS AND METHODS

Experiment Equipment: The method of cleaning bananas are as follows: setting up an experimental equipment as shown in Fig. 2, placing picked bananas on a tray for specialized use, putting the tray on the double-stranded roller conveyor (1) for delivering, opening solenoid valve through detection, induction and control of sensing devices when bananas reach the spray carriage (2), starting the pump (3) and washing bananas with water from high-pressure spray nozzle after flowing through the well-laid water pipe. The used water flows back to the tank. As it is pure water used in the system and physical filtration is applied in the filter unit, the washing process is free from chemical reagent and the water used for washing is recycled, thus food safety can be ensured in cleaning bananas and environmental pollution can be avoided.

DC-P3 full-automatic chromatic aberration meter produced by Changzhou Ruipin Precision Instrument Co., Ltd. was adopted to determine chromatic aberration, involving the following parameters: accuracy: $\Delta Y(\Delta X, \Delta Z) \leq 1.5$, $\Delta X, \Delta Y(\Delta Z) \leq 0.015$; stability: $\Delta Y \leq 0.15$; repetitiveness: $\Delta E \leq 0.05$; reproducibility: $\Delta E \leq 0.25$; and fatigue properties: $\Delta Y \leq 0.15$. GY-1 fruit pressure tester produced by Guangzhou Mingrui Electronic Technology Co., Ltd. was applied to determine the flesh firmness, involving the following parameters: probe size: 3.5 mm; measuring range: 2~15MPa; and measuring accuracy: 0.1MPa. Automatic submersible pumps of Sunsun brand were adopted as cleaning pumps. In particular, one model such as HQS10000 was used, the specific parameters of which was set out in Table 1.

Experiment Method: The traditional immersion method for cleaning bananas was followed in this experiment. Five bananas with marks were immersed in basins with same amount (2.5L) of 26.7□ pure water, respectively, then suspended in a room with temperature of 25.3□. The above experiment was repeated three times, taking the average of the experimental data and comparing the cleaned and uncleaned bananas. The measurement on flesh firmness and chromatic aberration of peel was carried out every three days for observing rot of bananas.

Spray Cleaning Experiment

Factors for Cleaning

Nozzle Arrangement: Generally speaking, nozzle arrangement has three types, including rectangle, triangle and square. Due to little difference between rectangle arrangement and square arrangement within the range of 850×600mm, the rectangle arrangement and triangle arrangement were used in the experiment only. Please refer to Fig. 3 for the nozzle arrangement.

Fig. 2: Experiment equipment

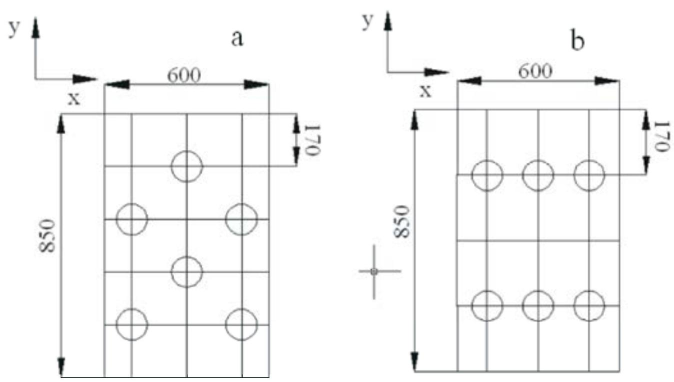

Fig. 3: Nozzle arrangement a. Triangle arrangement, b. Rectangle arrangement

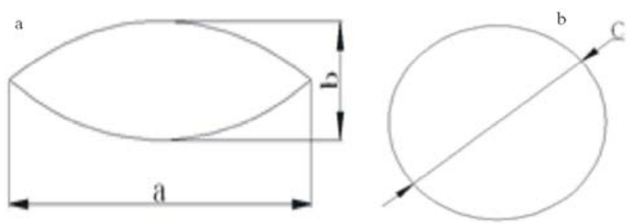

Fig. 4: Nozzle shape a. Sectorial nozzle, b. Round nozzle

Table 1: Water pump parameter

Model number	Rated power (W)	Max pressure(m)	Maximum flow(m^3/h)
HQS-10000	420	13.0	16.0

Table 2: Nozzle size

Height(mm)	a(mm)	b(mm)	c(mm)
300	300	112.5	187.5
400	400	150	250
500	500	187.5	312.5

Spray Height: As the impact of spraying on dirt of bananas peel varied according to spray height, the impact is greater when the height is lower. However, the spraying range decreases if the height is too low. In accordance with spraying structure of the cleaning system, three heights such as 500, 400 and 300mm were set up.

Nozzle Shape: Two kinds of nozzle shapes, round and sectorial, are commonly used, water sprayed out from which are circular spout and sectorial spout, respectively. At different height, shape and area of spraying were set out in Fig. 4 and Table 2.

Spray Angle: Included angle of spraying range of the round nozzle is 45°. Three kinds of spray angles were designed, namely, 90°, deflecting to the inner side by 22.5° and deflecting to the outer side by 22.5°, as shown in Fig. 5.

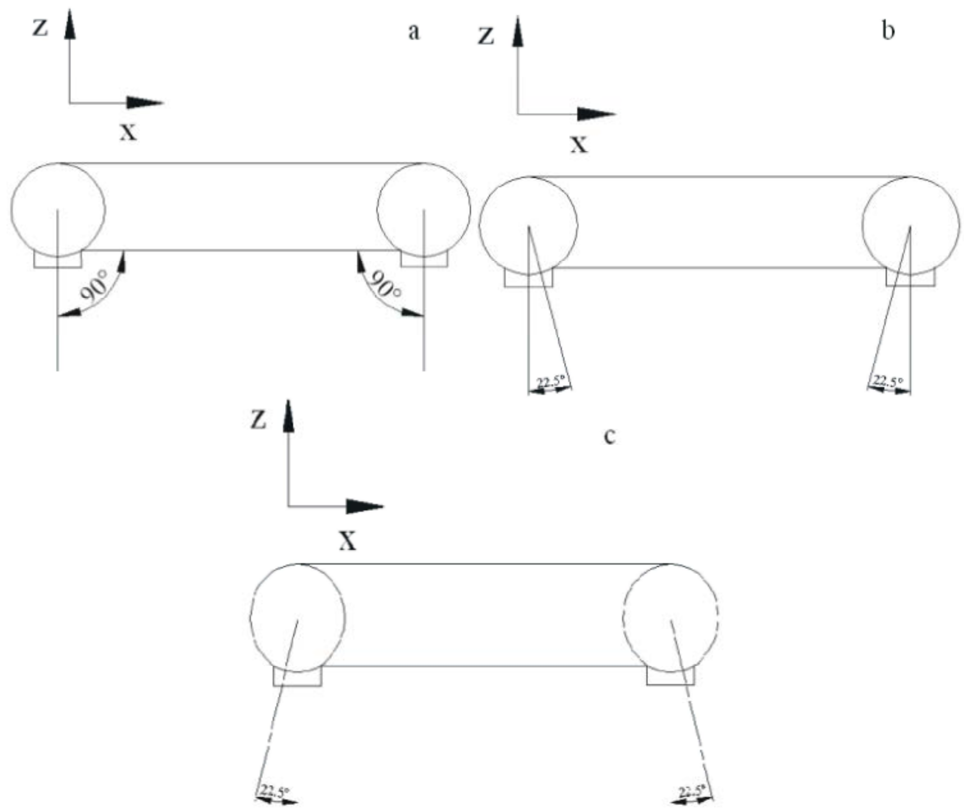

Fig. 5: Varied spray angles a. 90°, b. Deflecting to the inner side by 22.5°, c. Deflecting to the outer side by 22.5°

Conveying Speed: Conveying speed is controlled by frequency converter. The speed has impact on the time of spraying bananas. Upon calculation, four speed levels were 0.3986, 0.3286, 0.2610 and 0.1620m/s, respectively.

Procedures of Cleaning Experiment: Bananas with wet peel were placed into a barrel containing cement powder and the electric air compressor was used to supply air for 10 seconds, resulting that cement powder evenly adhered to banana peel. With adjustment of each main parameter in the cleaning system and start of the pump, bananas covered by cement powder were placed on wire netting for delivering on the roller conveyor through the spraying area and photos were shot from the same overlooking angle. The experiment was repeated three times. After cleaned bananas were photographed at the overlooking angle, photos were imported into the software photoshop. (As the experiment needs to calculate the percentage of its cleanliness, rather than to seek for its area with a scanner by setting up resolution, it is only necessary to make sure the camera shooting photos at the same angle relative to the bananas.). The software photoshop was applied to select the area of bananas covered and the area of cleaned bananas without adhering to cement powder, from which the number of pixels in the selected areas was obtained. In this paper, the cleanliness is defined as:

$$Cleanliness = \frac{Pixel\ of\ \ wash\ \ \ area}{Pixel\ of\ \ \ total\ \ \ area} \qquad (1)$$

The Taguchi Method: The procedures of the Taguchi method are as follows. Firstly, select proper quality characteristics and process parameters according to experimental analysis. Secondly, select proper orthogonal array to conduct the experiments. Thirdly, analyze the experimental results using the S/N ratio and statistical analysis of variance by SPSS software. Lastly, obtain the optimal process parameters by using SPSS software.

In order to meet the practical needs of quick cleaning, only one cleaning effect was analyzed in the Taguchi experiment. Nozzle shape, spray angle, spray height, conveying speed and nozzle arrangement were selected as the experimental factors. Experimental factors and levels are shown in Table 3. In the experiments, interaction between the factors was not considered and each experiment was repeated three times. The experiment samples amounted to 48 in total, with the cleanliness as its evaluation index.

Table 3: Factors and levels

	Factors				
Levels	Nozzle shape	Conveying speed (m/s)	Spray height (mm)	Spray angle (°)	Nozzle arrangement
Level- 1	Round	0.3986	300mm	Deflecting to the inner side by 22.5°	Triangle arrangement
Level- 2	Sectorial	0.3286	400mm	90°	Rectangle arrangement
Level- 3		0.261	500mm	Deflecting to the outer side by 22.5°	

Calculation of S/N: Cleanliness is the criterion of this experiment. A higher cleanliness means better parameter optimization. Therefore, the larger, the better-characteristic form is selected in this experiment. The formula is as follows [12]:

$$\frac{S}{N_i} = -10\log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right) \quad (2)$$

Calculation of ANOVA: The analysis of ANOVA is used to discuss the relatively important factor of all controllable factors on the cleanliness of the samples formed by cleaning banana and also to determine which one has the most significant effect. Parameters used in ANOVA are calculated by the following equations:

$$S_m = \frac{\left(\sum_{i=1}^{16}\eta_i\right)^2}{16} \quad (3)$$

$$S_A = \frac{\left(\sum_{i=1}^{4}\eta_{Ai}\right)^2}{N} S_m \quad (4)$$

$$S_r = \sum_{i=1}^{16}\eta_i^2 S_m \quad (5)$$

$$S_E = S_r \sum S_A \quad (6)$$

The various kinds of A are nozzle shape, conveyor belt speed, spray height, spray angle and nozzle arrangement. N is 3 in this work.

RESULTS AND DISCUSSION

Analysis on Chromatic Aberration: Chromatic aberration is a serious flaw in lens imaging. Chromatic aberration is simply the color difference occurred in the case of polychromatic light as the light source, while monochromatic light does not produce color difference. The main parameter for determining chromatic aberration is lightness difference (LD). If LD is positive, it indicates that the sample color is lighter than standard light (yellow is selected as the standard light in the experiment, thereby green and black are defined as lighter and deeper than yellow respectively in the measurement). If LD is negative, it indicates that the sample color is deeper than the standard light.

According to the natural rules, color of banana peel changes from green to yellow, finally goes to black as the picked bananas become mature and rotten. In the general trend, the value of LD continuously decreases. The relationship between days of storage and value of LD for comparing cleaned and uncleaned bananas is shown in Fig. 6.

As shown in Fig. 6, value of LD of cleaned bananas shows a downward trend with increasing days of storage, which means bananas change from green to yellow. Value of LD of uncleaned bananas declines with increasing days of storage and banana peel becomes darker as the time goes by. It declines fast in the first four days, while the rate of decline tends to gentle from the fourth day to the sixth day, because banana peel changes from green to yellow and gradually turns to black in the first four days. When it comes to the fourth day, the whole banana almost becomes black. Therefore, as the time goes by, banana peel hardly changes, resulting that the curve representing uncleaned bananas almost remains the same from the fourth day to the sixth day, which is gentle and tends to be a linear. In addition, value of LD of uncleaned bananas declines fast, the decrease rate of which is more than double of that of cleaned bananas, due to the fact that peel of uncleaned bananas has more microbes and bacteria rotting the peel and pulp in a faster manner as compare with the cleaned bananas.

Analysis on Flesh Firmness: The relationship between the days of storage and flesh firmness is shown in Fig. 7. According to change law, the fresh firmness of banana declines with its maturity. As shown in Fig. 7, flesh firmness of cleaned bananas changes in line with maturity law of bananas that they become softer as the time goes by. However, flesh firmness of uncleaned bananas experiences a linear decrease in the first two days.

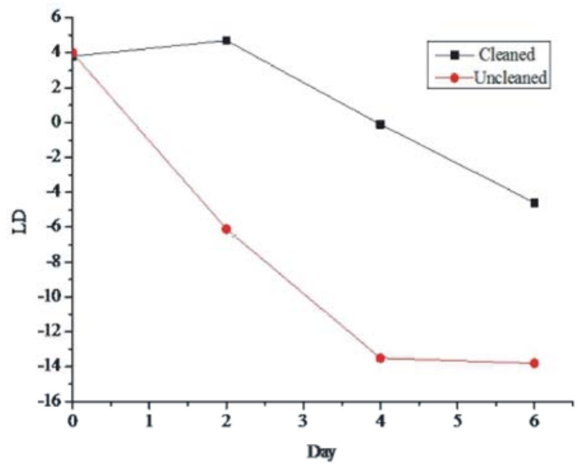

Fig. 6: Relationship between days of storage and value of LD

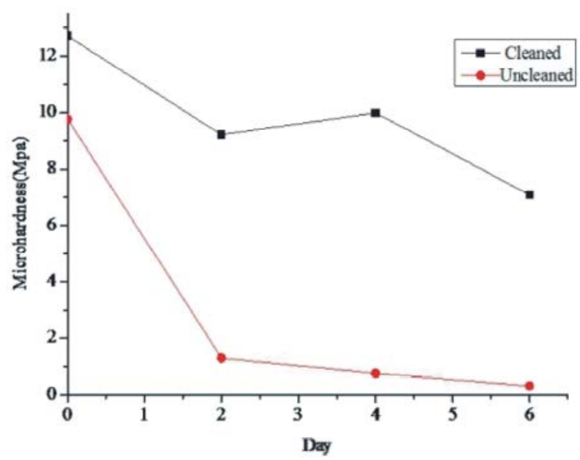

Fig. 7: Relationship between the days of storage and flesh firmness

Two days later, the flesh firmness declines gently in a narrow range, which can be approximately treated as constant, which is attributable to the fact that after two days of storage, uncleaned bananas are of full maturity and the flesh firmness remains unchanged. Fig. 7 also indicated that as days of storage increase, flesh firmness of cleaned bananas declines slower than that of uncleaned bananas. At the same time of storage, flesh firmness of cleaned bananas apparently higher than that of uncleaned bananas.

As shown in Fig. 6, the color of uncleaned bananas changed significantly after stored for four days and as shown in Fig. 7, flesh firmness of uncleaned bananas suffered marked change in the second day. Fig. 6 and 7 indicated that flesh firmness of uncleaned bananas rots faster than peel. As for cleaned bananas, value of LD and flesh firmness change without obvious sequence. Both value of LD and flesh firmness of cleaned bananas are remarkably greater than that of uncleaned bananas. As shown in Fig. 6 and 7, cleaning can slow down deterioration of flesh and peel of bananas at the same time, leading to a better fresh-keeping effect of cleaned bananas than uncleaned bananas. Therefore, for a longer preservation time, bananas shall be cleaned. A better cleaning effect is to be achieved from optimization of parameters of cleaning with pure water.

Factors of Taguchi Experiment: From….[6], Table 4 can be obtained. Table 4 illustrates the S/N results of the 48 bananas generated from the experiment upon measurement of their cleanlinesses. According to analysis on range of S/N, the influence of factors on the cleanliness is arranged in a row such as nozzle shape > spray angle > spray height > conveyor belt speed > nozzle arrangement, in an order of significance.

ANOVA Analysis: Table 5 illustrates ANOVA analysis based on application of the formulas in Eqs. (3)–(6), with S/N as an indicator. The critical F value is 95% when α=0.05 and the confidence level is $F_{0.05,\ 2,7}$=4.74. Since F values of factors such as nozzle shape and spray angle are greater than 4.74, both of them are significant factors in controlling the cleanliness, while conveyor belt speed, spray height and nozzle arrangement have marginal effect.

Model Analysis: As the nozzle shape, spray angle and nozzle arrangement in the Taguchi experiment are nominal categorical variables, dummy variables are firstly coded, then model is analyzed with SPSS software. For example, the dummy variables of spray angle are IA1 (deflecting to the inner side by 22.5°) and IA2(vertically downward). IA1 represents the difference between deflecting to the inner side by 22.5° and deflecting to the outer side by 22.5°. When spray angle 1 is selected, IA1=1, IA2=0 and the rest can be treated in the same manner. Therefore, spray angle 3 means IA1= IA2=0. Table 6 shows the cleanliness derived from ANOVA analysis. The same table also shows R2 and adjusted R2. The completed model R2 is 0.901, fitting degree of which is relatively high.

A Mathematical model was developed to estimate the cleanliness for optimization purpose in this paper. The mathematical model is as follows:

$$Cleanliness = -0.220A^2 + 0.208A - 0.306 \quad (7)$$

In which,

$$A = 3.963 - 2.074NS_2 - 11.380CBS + 0.007SH + 2.599IA_1 + 0.521IA_2 + 1.132NA_2.,$$
$$NS = Nozzle\ shape, CBS = Conveyor\ belt\ speed, SH = Spray\ height.$$

Table 4: Design matrix and experimentally recorded responses for cleanliness and the corresponding S/N

	Factor					Responses			
Std	Nozzle shape	Conveyor belt speed	Spray height	Spray angle	Nozzle arrangement	Cleanliness/%			Mean S/N
1	1	1	1	1	1	91.1	89.2	95.6	-0.4620
2	1	1	1	2	1	87.5	77.4	85.8	-1.5974
3	2	1	2	1	1	78.2	74.7	79.4	-2.2302
4	2	1	2	2	1	50.5	51.0	49.4	-5.9710
5	2	2	1	1	1	91.5	84.2	86.7	-1.1785
6	2	2	1	2	1	67.6	61.0	65.2	-3.8190
7	1	2	2	1	1	96.2	88.7	93.8	-0.6547
8	1	2	2	2	1	78.7	88.7	87.5	-1.4527
9	1	2	2	2	2	90.4	90.1	92.7	-0.8149
10	1	2	2	3	2	77.8	83.2	88.5	-1.6371
11	2	2	3	2	2	61.6	66.8	67.2	-3.7357
12	2	2	3	3	2	63.0	66.3	65.7	-3.7482
13	2	3	2	3	2	87.5	81.6	83.5	-1.5047
14	2	3	2	3	2	63.2	67.1	66.0	-3.6924
15	1	3	3	2	2	94.0	90.6	93.5	-0.6619
16	1	3	3	3	2	82.0	88.0	83.1	-1.4887
Mean S/N-1	-1.0962	-2.5652	-1.7642	-1.1314	-2.1707				
Mean S/N-2	-3.2350	-2.1301	-2.2447	-2.5789	-2.1605				
Mean S/N-3		-1.8369	-2.4086	-2.4142					
Range	2.1388	0.7283	0.6444	1.4475	0.0102				
Optimal combination	1	3	1	1	2				

Table 5: Analysis of the variance for cleanliness

Source	Sum of squares	Degree of freedom	Mean square	F	
Nozzle shape	16.063	1	16.063	18.467	Significant
Conveyor belt Speed	1.564	2	.782	.899	
Spray height	2.367	2	1.183	1.360	
Spray angle	8.657	2	4.328	4.976	Significant
Nozzle Arrangement	1.793	1	1.793	2.061	
Error	5.219	6	.870		
Total	111.592	15			

Table 6: ANOVA analysis

SOV	Sum of squares	Degree of freedom	Mean square	F	Prob.>F
Regression	35.702	6	17.851	63.888	<0.001 (signifcant)
Residual	3.912	8	0.279		
Total	39.614	14			
	$R^2 = 0.901$		Adj $R^2 = 0.887$		

Table 7: Verification of model

	Factor					Responses				
Std	Nozzle shape	Conveyor belt speed	Spray height	Spray angle	Nozzle arrangement	Experimental clearness/%	Experimental S/N	Theoretical S/N	Relative error	Mean error
1	1	3	1	1	2	95.5	-0.41	-0.46	10.8%	8.7%
2	1	1	3	1	2	41.3	-7.65	-8.32	8.1%	
3	2	1	1	3	1	94.3	-0.51	-0.55	7.3%	

Validation of the Models: In order to confirm the adequacy of the developed models, three confirmation experiments were carried out using new randomly selected test conditions, each with in the experimental range defined earlier in Section 2. Table 7 shows the test conditions, the actual values, the predicted values and the percentages of error. The results show that the maximum error percent for cleanliness is 10.8% which is in reliable agreement, therefore the models are valid. From Table 7 we can find that the percentage prediction error of the model in this study is 8.7%.

Optimization: It is necessary to run an optimization study to find out the optimal processing conditions at which a desirable cleanliness of bananas can be achieved. The evaluation criterion is to reach maximum cleanliness with no limitation on the processing parameters. As shown in Table 4, with a confidence of 95%, the optimal combination is $A_1B_3C_1D_1E_2$, namely round nozzles, 0.3986 m/s of conveyor speed, 300mm of spray height, deflecting to the inner side by 22.5° and a rectangle arrangement of nozzles, resulting in an actual cleanliness of 95.5%.

CONCLUSIONS

With flesh firmness and chromatic aberration of peel as indicators of the experiment in the paper, the impact of cleaning on quality of bananas was studied and the necessity of cleaning bananas was discussed. By studying the factors affecting cleanliness of cleaned bananas, a group of optimal parameters for cleaning bananas were achieved and verified. The experimental results indicate that:

- Cleaning has essential effect on fresh-keeping of bananas that flesh firmness and peel color of cleaned bananas are clearly better than that of uncleaned bananas when stored under the same environment for the same period of time.
- The most significant processing parameter affecting the cleanliness is nozzle shape.
- As drawn from Taguchi experiment, the optimal processing parameters for cleaning bananas in a single time including: water pump with a power of 420W and round nozzle deflecting to the inner side by 22.5° at a spray height of 300mm in a rectangle arrangement of nozzles with a conveyor speed of 0.3986m/s.
- When a cleaning experiment was carried out with the optimal experiment parameters, cleanliness of cleaned bananas was 95.5%, satisfying actual needs of production, thus pure water can replace of chemical reagent of immersion cleaning.

ACKNOWLEDGEMENTS

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