MAKALAH PENELITIAN

OPTIMAL HEAT TREATMENT TO DELAY THE RIPENING PROCESS OF TOMATO USING GENETIC ALGORITHMS

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Summary

An optimal pattern of the heat treatment for tomato was investigated using an intelligent control technique consisting of neural networks and genetic algorithms. An objective function was given by the reciprocal number of the color development from green to red for evaluating the ripening of tomato. The control process was divided into *l*-step. Firstly, the color development was identified using neural networks. Then, *l*-step set-points of temperature which maximize the objective function were sought through a simulation of the identified model using genetic algorithms. The genetic algorithms allowed an optimal heat treatment to be successfully determined by simulation of an identified neural network model. Finally this optimal heat treatment was applied to an actual system. The result showed that the optimal heat treatment indicated better result in maintaining the color development of fruit than the conventional one.

Keywords: heat treatment, genetic algorithms, intelligent control

INTRODUCTION

Recently, heat treatment technique has become an alternative to maintain the quality of fruit during storage. It inhibits *ethylene* production, *lycopene* synthesis and *chlorophyll*, and all of these factors influence ripening process of fruit (Bigg et al., 1988; Lurie and Klein, 1992; McDonald et al., 1996). It is also reported that heat treatment can maintain better firmness of apple (Tu and Baerdemaker, 1996). Storage heat treatment can be done into a short term (up to 60 minutes in water) at 45-60°C (Klein and Lurie, 1990) and a long term (12 hours to 4 days in air) at 38-46°C (Lurie and Klein, 1992). These reports have proved that the quality of fruit during storage can be maintained by combining both heat treatment and cooling treatments.

The problem is that it is not well known how to decide the optimal condition of heat treatment for maintaining the quality of fruit effectively because the dynamics of the heat treatment are characterized by complexity and uncertainty. For control, the use of fruit responses are essential. This concept is called "Speaking Fruit Approach (SFA)" (Baerdemaker and Hashimoto, 1994).

Intelligent control technique consisting of neural networks and genetic algorithms for optimizing complex agricultural control systems have been developed for recent years (Morimoto et al., 1995a and 1996) for fruit storage processes (Morimoto et al., 1995b). Neural networks, with their own high learning ability (Chen, et al., 1990; Hunt, et al., 1992), have the capability for identifying complex non-linear systems. On the other hand, genetic algorithms are effective for finding an optimal value in the complex optimization problem by simulating the biological evolutionary process, based on genetical crossover and mutation. (Goldberg, 1989).

The aim of this study is to find out an optimal heat treatment to delay ripening process using intelligent control approaches such as neural networks and genetic algorithms.

MATERIALS AND METHODS

Experimental

Tomatoes (*Lycopersicon esculentum* Mill. cv. Momotaro) which are all mature green and of uniform size and color were stored in a storage chamber (Tabai-espec, LHU-112M), in which the temperature and relative humidity can be controlled at accuracy of 0.1°C and 2%, respectively. The color development of tomatoes was observed during ripening using a colorimeter (Minolta, CR-200b). The LCH method is used because this method provides a better correlation with the human color perception.

Methodology

The technique to determine optimal heat treatment is shown in **Figure 1.** In this method, neural network was first utilized to identify the ripening (color development) of fruit as affected by temperature. The dynamic model is obtained through this identification. Then, genetic algorithms was used to find out an optimal set-point at which it minimized the color development of fruit during storage. The set-point which had been decided through simulation of the identified model was utilized to setup the controller to control storage environment temperature of fruit. These procedures were repeated to follow the time-varying characteristics of the dynamic system.

The first step was to identify the color development, as affected by temperature, using neural networks. For this purpose, a three-layer neural network was used for identification, as shown in **Figure 2.** An effective way to identify the cumulative responses such as water loss of fruit had been developed (Purwanto et al., 1995). For the dynamic identification, the (n+1)*th* time series of input (temperature) as stated as {T(k), T(k-1), ..., T(k-n)}, a linear data d(k) and (n) *th* past time series of the output (color development) as stated {C(k-1), ..., C(k-n) } were applied to the input layer and the current values of color

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development, C(k), was used as reference value (k : sampling time, n : number of system parameter). The system parameter number (n) and the neuron number in hidden layer were determined through cross-validation.

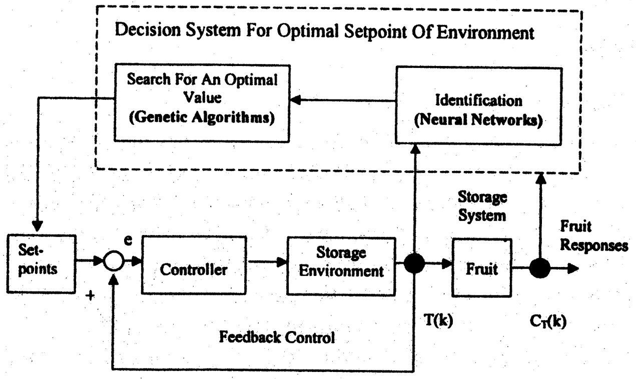


Fig. 1. The Technique to Determine An Optimal Heat

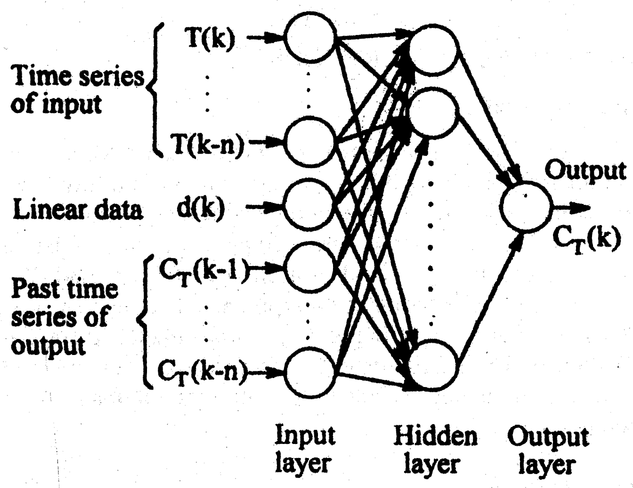


Fig. 2. A Three-Layer Neural Network was Used for Identification

The second step was to determine an optimal heat treatment through simulation of the identified model using genetic algorithms. In this simulation it was assumed that the control process consisted of l-step (that is, l-step decision process). Therefore, an individual genetic algorithm application was defined as l-step set-points of temperature during storage and these were coded as a 6 bit binary strings as stated as follow :

$$\text{Individual } I = t_{l1}, t_{l2}, \ldots t_{li} = 100100\ 001001 \ldots 101010 \quad (1)$$

In this study the constraint of temperature was $5°C \leq T(k) \leq 35°C$ while temperatures of $0°C \leq T(k) \leq 63°C$ were obtained from the 6-bit binary digit.

On the other hand, the fitness, F(T), meaning that the objective function had been optimized was given by reciprocal number of P(t), which was the sum of the last four values in the cumulative response of color development.

$$P(T) = \alpha . \sum_{K=N-3}^{N} C_T(k) + \beta . \sum_{k=N-3}^{N} \{C_T(k) - C_T(K-1)\} \quad (2)$$

$$F(T) = 1/P(T) \quad (3)$$

Notation :

- $C_T(k)$: Value of color development at time k under temperature T.
- N : Number of data
- k : Sampling time
- T : Temperature (°C)
- α and β : Coefficients for two evaluators.

A process to obtain an optimal value can be described as follows. Step 1 : The initial population consisting of Ni sort of individual was generated at random. Step 2 : Crossover and mutation operators were applied to those individuals. Through this operation, N ($=N_i + N_c + N_m$) sorts of individual were obtained (N_c and N_m represent individual numbers, newly created by crossover and mutation, respectively). Step 3 : The fitness of each individual was calculated using neural network model. Step 4 : Several individuals with higher fitness were selected and retained for the next generation. **Figure 3** showed the procedure for obtaining an optimal value using a genetic algorithms.

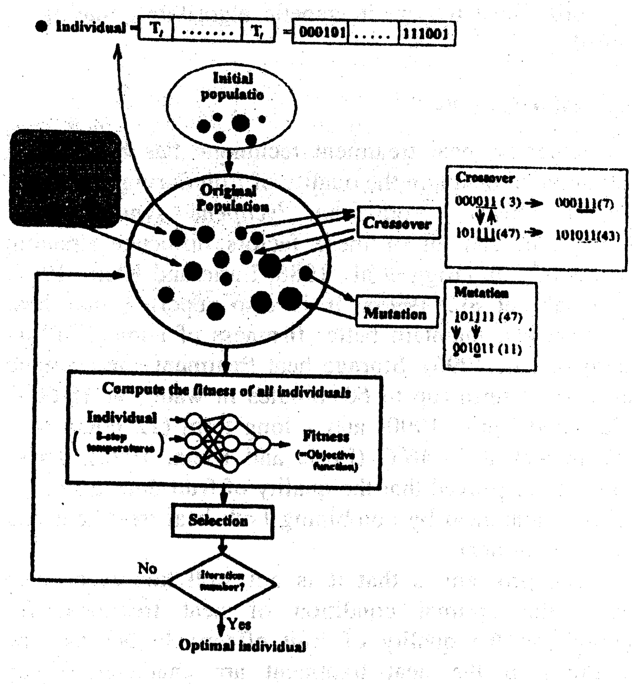


Fig. 3. The Procedure for Obtaining An Optimal Value Using A Genetic Algorithms

An optimal value can be obtained by repeating these procedures. Furthermore, the control process was divided into 8 steps, because the storage period of tomato was 8 days. The optimization problem in this study was to determine the 8 step set-points of temperature which maximize the fitness (objective function).

RESULTS AND DISCUSSION

Actual Color Development And Its Identification

Changes in the color development of tomato, as affected by temperature, during storage are exhibited in **Figure 4.** The color development increases with temperature. Under the high temperature (35°C), however, the color development can be seen smaller than that under the 25°C. The largest decay of the color development occurs when fruit is kept at 25°C, but the color development can be delayed with minimum changes after the temperature is kept at 5°C. In this study, for convenience, the color development is treated as an increasing response by revising the original response and initiate 0° as an initial value while it is usually expressed by the change of hue angle from 180-0°C.

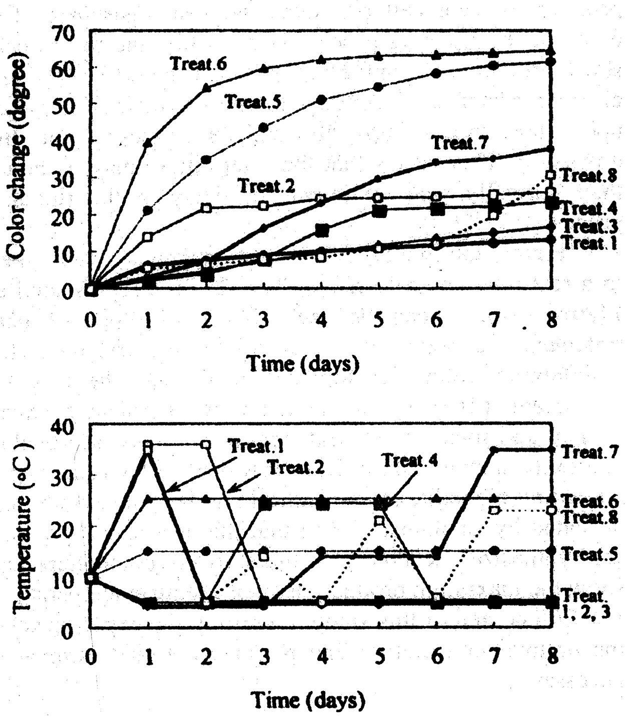


Fig. 4. The Color Development of Tomato During Heat Treatment

Further, responses of the color development, as affected by temperature, are identified using a three-layer neural network. For identification, cross-validation is usually carried out. The data of **Figure 4**, are divided into a training data set for training the neural network and a testing data set for determining the number of system parameter and the hidden neuron number of the neural network. In this study, however, the system parameter number was given as 1 because the data number (=8) is scant for identification. This procedure has been confirmed to be reasonable (Purwanto et al., 1995). The relationship between the hidden neuron numbers and the estimated error (=RMSE), obtained from the testing data set, are presented in **Figure 5.** This result shows that neural network model constructs 4 hidden neuron numbers and 1 system parameter number gives a minimum error. Based on this valid result it can be concluded that the neural network model is valid for the identification of storage heat treatment purpose.

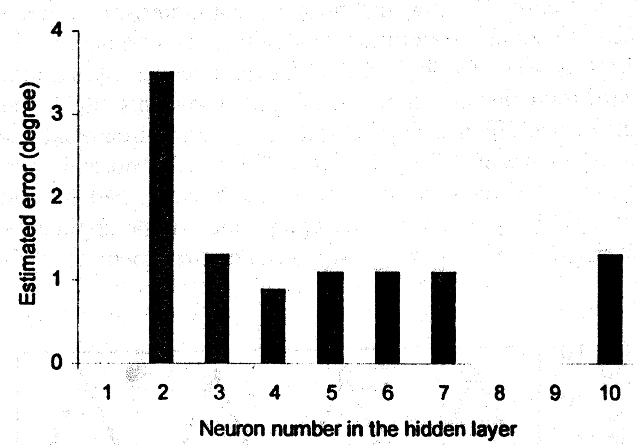


Fig. 5. The Relationship Between The Hidden Neuron Number and The Estimated Error

Searching For An Optimal Heat Treatment.

The next step is to determine the 8 step set-points of temperatures which maximize the objective function (=fitness) using genetic algorithms. **Figure 6** show evolution curves in searching for an optimal value. In the figure, 50 individuals were added to the original population from another population and, moreover, the crossover was conducted between the another population and the original population (treatment 2) and the case without addition of individuals from another population was carried out and, moreover the crossover was conducted within original population (treatment 1) are represented. The mutations in both cases were conducted within an orignal population. The crossover and mutation rates are 0.8 and 0.6, and the weights α and β are 1.0 and 1.0, respectively. The selection technique is based on an elitist strategy which remains an individual with maximum fitness for next generation in each generation. From this figure, it is found that evolution with a high diversity gives a best result. The fitness increases suddenly with generation number, then reaches the maximum in 15th generation. An individual with this maximum fitness is an optimal value.

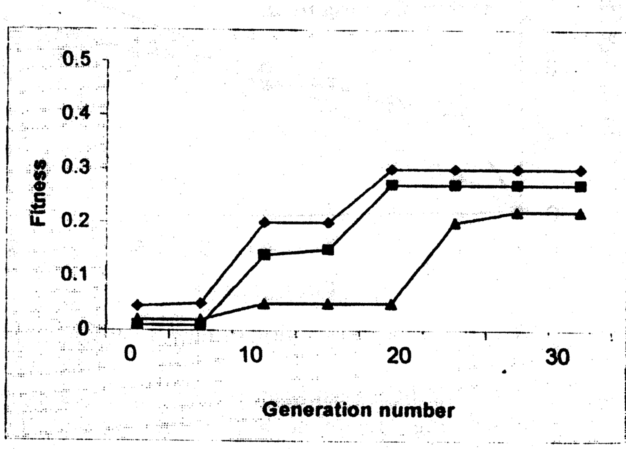
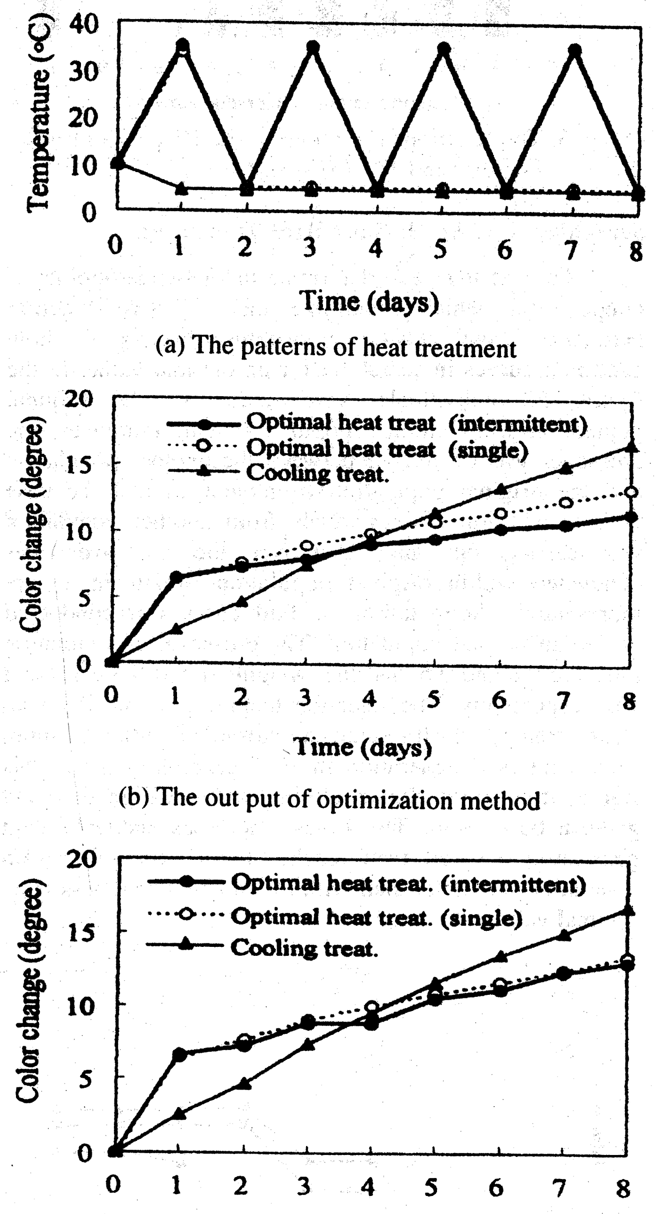


Fig. 6. Evolution curves in searching for an optimal value

Optimal Heat Treatment And Its Control Performance.

Figure 7 show the normal heat treatment, optimal heat treatment (intermittent application) obtained using intelligent approach, and cooling treatment in the relation with the color development of fruit. From this figure, the difference effect of temperature for cooling treatment and heat treatment. Can be considered the normal heat treatment here is the treatment that is conducted for one time at the first stage of storage period (single application at 35°C then continued with cooling treatment at 5°C).



(a) The patterns of heat treatment

(b) The out put of optimization method

(c) The output of application of heat treatment

Fig. 7. The normal heat treatment, optimal heat treatment, and Cooling Treatment in The Relation with The Color Development of Tomato

In this case, the color development increases suddenly for a while and then continuously declines with a minimum change. This result is better than that a fruit stored at storage cooling treatment. Based on this result, it can be depicted that the heat treatment has a significant effect for maintaining color development. Furthermore, the color development of both types of heat treatment indicates that the intermittent application of heat treatment real effect in maintaining the color development.

It is well-known that an exposure of fruit to one stress, such as heat stress, can elicit responses similar to the exposure to other stresses and sometimes protect the fruit against another stress. Some types of proteins called 'heat shock proteins (hsps)' are synthesized in their cells when living organism are exposed to shift-up temperature (Craig and Gross, 1991). Synthesizing the heat shock proteins in each cell promotes the heat resistance. The delay of the ripening process is probably due to the heat shock protein resisting the heat stress. The synthesis of this class of proteins, in contrast to most proteins, increases upon temperature up-shift and decreases upon the downshift. This means that the intermittent may be better than normally heat treatment for delaying the ripening process.

Finally the two types of heat treatments were applied to a real time control system. The result is represented in **Figure 7(c).** It can be seen that both types of heat treatment are better than that of cooling treatment for maintaining color development. However, there is no significant difference in the color development between normal and intermittent heat treatments. This is probably due to the temperature of heat treatment (35°C) that is not a maximum condition for synthesizing heat shock proteins as stated by Lindquist (1980) that the heat shock proteins are synthesized according to the shift-up temperature and show the maximum production at an adequate temperature. For further step of this study, therefore, the experiment on the optimal temperature and period for heat treatment is necessary.

CONCLUSION

In this study an optimal condition of heat treatment for tomato was investigated using an intelligent control technique consisting of neural networks and genetic algorithms. A three-layer neural network was effective for identifying the fruit responses as indicated by color development, as affected by temperature including heat treatment. It was also found that the genetic algorithm allowed the optimal set-points to be successfully determined using simulation of the identified neural network model. In this case maintaining the diversity of the population at a high level shortened the search time for an optimal value. The optimal heat treatment obtained here was intermittent, while the conventional one was only one treatment at the first stage. This optimal heat treatment yielded better results on ripening than the conventional one in the actual application.

References

Biggs, M.S.,R.William, and A. Handa : Biological basis of high-temperature inhibition of ethylene biosynthesis in ripening tomato fruit. Physiologia Plantarum, 72 : 572-578 (1998).

Chen, S., S.A. Billings, and P.M. Grant : Non-linear system identification using neural networks. International Journal of Control, 51(6) : 1191-1214 (1990).

Craig, E.A. and C.A. Gross : Is hsp70 the cellular thermometer ?. TIBS, 16-April 1991. Elsevier Science Publishers Ltd., UK (1991).

De Baerdemaker, J. and Y. Hashimoto : Speaking fruit approach to the intelligent control of the storage system. In : Proc. Of 12th CIGR World Congress, Vol. : 1, pp. : 190-197, (1994).

Goldberg, D. : Genetic algorithms in search, optimization and machine learning. Addison-Wesley (1989).

Hunt, K.J., D. Sbarbaro, R. Zbikowski, and P.J. Gawthrop : Neural networks for control systems survey. Automatica, 28(6) : 1083-1112 (1992).

Klein, J.D. and S. Lurie : Prestorage heat treatment as a means of improving post-storage quality of apples. Journal of America Society of Horticultural Science, 115(2) : 265-269 (1990).

Lindquist, S. : Varying patterns of protein synthesis in *Drosophila* during heat shock proteins for regulation. Developmental Biology, Vol. : 77, pp. : 463-479 (1980).

Lurie, S. and J.D. Klein : Ripening characteristics of tomato stored at 12°C and 2°C following a prestorage heat treatment. Scientia Horticulturae, 51 : 55-64 (1992).

Morimoto, T,.T. Torii, and Y. Hashimoto : Optimal control of physiological processes of plants in a green plant factory. Control Engineering Practice, Vol. : 3(4), pp. : 505-511 (1995a).

Morimoto, T., W. Purwanto, and Y. Hashimoto : Intelligent control simulation for optimization of storage process. Journal of SHITA, Vol. : 7(2), pp. : 91-96 (1995b).

Morimoto, T., K. Hatou, and Y. Hashimoto : Intelligent control for plant production system. Control Enggineering Practice, Vol. : 4(6), pp : 773-784 (1996).

McDonald, R.E. and T.G. Mc. Collum : Prestorage heat treatments influence free sterols and flavor volatiles of tomatoes stored at chilling temperature. Journal of American Society of Horticultural Science, 121(3) : 531-536 (1996).

Purwanto, W., T. Morimoto and Y. Hashimoto : Simulative estimation for the identification of the cumulative response of a plant using neural networks. Journal of SHITA, 8(2), 112-118 (1995).

Tu, K., and J. De Baerdemaker : A Study of pre-storage heat treatment effect on apple texture. In : Proceedings of International Converence on Agriculture Engineering, Vol : 2, pp. 877-878 (1996).