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Optimization of process parameters for banana ripening using ethylene gas

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ABSTRACT

The study on organic ripening of banana (*Musa* sp. var 'Robusta') fruit was carried out to optimize the best suitable combination of ethylene concentration, temperature and relative humidity. Process parameters were optimized using the design-expert version 8.0.6 software (Stat-Ease Inc, Minneapolis, USA) and applying factorial methodology to the experimental data. Quality parameter of well ripen banana were taken as standard for comparing the experimental results. The temperature, relative humidity, ethylene gas concentration and duration of ripening were observed to have profound influence on ripening characteristics of banana fruit. Among all, the combination of 40°C temperature, 80% relative humidity and 90 ppm ethylene concentration was found optimum for producing ripening effect after 72 hours with quality parameters *i.e.* total soluble solid (17.68%), pH(4.79), L*(60.26) a* (12.35) and b* (37.73) which were very close to values of standard sample. The study concluded that ripening of banana can be performed with the help of ethylene gas in closed chamber within three days.

Key words: *Musa sp*., temperature, relative humidity.

INTRODUCTION

Banana (*Musa sp.*) is the most nutritious and oldest abundantly cultivated tropical fruit crop, which has a rare combination of energy value, tissue-building elements, essential nutrients including minerals, and vitamins. India ranks first in the world with the 29163 thousand MT banana production from 858 thousand ha area during 2016-17 (NHB, 9). During ripening fruits attain their desirable flavour, quality, colour, palatable nature and other textural properties mainly due to conversion of starch to sugar. Generally, the most of the climacteric fruits in India are ripened artificially using calcium carbide which has been reported to contain a high amount of sulfur and a trace amount of arsenic and phosphorous (Islam *et al.*, 6). Recent reports on health issues pertaining to artificial fruit ripening agents (Fattah and Ali, 4, Siddiqui and Dhua, 11, Ur-Rahman *et al.*,13) justify the use of natural ripening agents as an alternative of calcium carbide. Ethylene, a ripening hormone produced by the plant plays a major physiological role in the ripening process and thus, can be used as a controlled treatment for fruit is to achieve the aesthetic standards and characteristic fruit quality (Barry and James, 2, Kulkarni *et al.*, 8). Ethylene application enhances fruit flavour and aroma through promoting ripening (Saltveit, 10, Watada, 15). Therefore, the present study was undertaken to investigate the effect of process variables *viz*., ethylene gas concentration, temperature, humidity and duration on ripening quality parameters of banana i.e. colour value (L*, a*, b*), total soluble solid (TSS) and pH with specific objective of optimization of process variables for organic ripening of banana.

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MATERIALS AND METHODS

Unripen banana (Musa sp var 'Robusta') of maturity stage of "1" were selected for ripening study (Gomes *et al.*, 5). Experimental trials were carried out during 2016-17 using environmental chamber (KI-213; khera, India) which was connected with ethylene gas cylinder of 10% purity. Concentration of ethylene gas was measured with the help of chemical sensors-based ethylene meter (Bioconservacion, Spain) with a sensitivity of 0.1 ppm. Banana samples were kept in environmental chamber and required amount of ethylene gas was fed into environmental chamber by opening control valve. The ripening experiments were conducted for different combinations of process parameters *viz.*, temperatures (30 and 40ºC), relative humidity (70, 80 and 90%), ethylene gas concentrations (70, 80 and 90 ppm). The desired temperature, relative humidity (RH) and concentration of ethylene gas was maintained and monitored at an interval of 6 hours during experiment.

The ripening quality parameters *i.e.* colour value, total soluble solid (TSS) and pH of fruits during ripening study were measured and recorded at an interval of 24 hours till fruits got fully ripen. Colour

value (L*, a*, b*) was measured using Hunter Lab Colorimeter (model- NCFLX/DIFF, CFLX-45). TSS was determined in terms of °Brix using hand held refractometer (RHB-18ATC; ERMA, Japan). The pH of fruits under study was measured by digital pH meter (Eutech, pH Testr 2). The ripening quality parameters of well ripen banana purchased from the local market were analyzed and taken as standard (TSS-16.5, pH-4.8, L*-58.58, a*-14.78 and b*-37.58) for comparing the effect of the ripening parameters. The best suitable combination of ethylene concentration, temperature and relative humidity for banana ripening was optimized using the design-expert version 8.0.6 software (Stat-Ease Inc, Minneapolis, USA) and applying numerical multi responses optimization technique to the experimental data. The desired goals for each factor (RH, temperature, ethylene concentration and ripening period) and response (TSS, pH, Colour value L*, a* and b*) were allotted as shown in Table 3. The equal importance of '3' was given to all the 3 process parameters and 5 responses.

RESULTS AND DISCUSSION

TSS was found to increase gradually from 1.9°Bx to 12.69, 13.68, 14.24°Bx when ripening period increased 0 to 72 hours for the ethylene gas concentration 70, 80 and 90 ppm, respectively during ripening of banana at temperature of 30°C and 70% RH. Similarly, TSS of banana increased gradually from 1.9°Bx to 13.38, 14.82, 15.40°Bx for RH of 80% and 1.9°Bx to 14.24, 15.37, 16.10°Bx for RH of 90% when ripening period increased 0 to 72 hours for the ethylene gas concentration of 70, 80 and 90 ppm, respectively at 30°C temperature (Table 1). The data presented in Table 2 revealed that TSS of banana fruit followed the same trend during ripening study at 40°C temperature. TSS of banana during ripening at 70% RH gradually increased from 1.9°Bx to 13.90, 14.80, 15.82°Bx when ripening period increased 0 to 72 hours for the ethylene gas concentration 70, 80 and 90 ppm, respectively. Similarly, for 40°C temperature the TSS of banana increased gradually from 1.9°Bx to 14.10, 15.90, 16.76°Bx for 80% RH and 1.9°Bx to 15.10, 16.87, 17.80°Bx for 90% RH when ripening period increased from 0 to 72 hours for the ethylene gas concentration of 70, 80 and 90 ppm, respectively. The data presented in Table 1 and 2 revealed that TSS of banana fruits increased with the increase in duration for all combination studied. This may be due to conversion of starch into sugar by hydrolysis. Findings are in confirmation with results reported by Ahmed *et al.*, 1, Khurnpoon *et al.*, 7; Soltani *et al.*, 12; Venkatram and Pandiarajan, 14.

Table 1 shows that pH of banana was found to decrease gradually from 5.2 to 4.9, 4.9, 4.8 with increase in ripening duration from 0 to 72 hours for the ethylene gas concentration 70, 80 and 90 ppm, respectively, during ripening of banana at 30°C temperature and 70% RH. Similarly, the pH of banana decreased gradually from 5.2 to 4.8, 4.8, 4.7 for combination of 30°C temperature and 80% RH and from 5.2 to 4.9, 4.8, 4.7 for 30°C and 90% RH when ripening period increased from 0 to 72 hours for the ethylene gas concentration of 70, 80 and 90 ppm, respectively. It can be observed from Table 2 that during ripening study at 40°C temperature and 70% relative humidity, the pH of banana gradually decreased from 5.2 to 4.9, 4.8, 4.8 when ripening period increased from 0 to 72 hours for the ethylene gas concentration 70, 80 and 90 ppm, respectively. Similarly, during ripening at 40°C, the pH of banana fruit was found to decrease gradually from 5.2 to 4.8, 4.8, 4.7 for 80% RH and from 5.2 to 4.8, 4.7, 4.7 for 90% RH when ripening period increased from 0 to 72 hours for the ethylene gas concentration of 70, 80 and 90 ppm, respectively. The pH of banana fruits was found to decrease with the increase in ripening period for all experimental trials. Similar results were reported by Ahmed *et al.*, 1; Kulkarni *et al.*, 8 and Soltani *et al.*, 12.

The data presented in Table 1 reveals that the L* value of banana increased gradually from 37.20 to 51.19, 52.98, 53.84 during ripening at 30°C temperature and 70 % RH with increase in duration from 0 to 72 hours for the ethylene gas concentrations of 70, 80 and 90 ppm, respectively. Similarly, for combination of temperature and relative humidity as 30°C & 80 % and 30°C & 90 %, the L* value of banana increased gradually from 37.20 to 53.92, 54.82, 56.03; 37.20 to 55.96, 56.12, 57.27 when ripening period increased from 0 to 72 hours for the ethylene gas concentration of 70, 80 and 90 ppm, respectively.

It is clear from Table 2 that the L* value was found to increase gradually from 37.20 to 56.40, 57.30, 58.12 with increase in ripening period from 0 to 72 hours during ripening at 40°C temperature and 70 % RH for the ethylene gas concentration 70, 80 and 90 ppm, respectively. Similarly, for other combinations of RH as 80 and 90 % at 40°C temperature, the L* value of banana gradually increased from 37.20 to 57.60, 58.27, 59.20 and 37.20 to 58.68, 59.40, 60.61 when ripening period increased from 0 to 72 hours for the ethylene gas concentration of 70, 80 and 90 ppm, respectively. During ripening, the green dark colour of banana changed into yellow colour so the brightness of colour of banana peel increased which implicating the increment in the L value.

Table 1. Effect of different process parameters on quality of banana during ripening at 30°C.

Temp. °C	RH (%)	Ethylene concn. (ppm)	Ripening period (h)	L*	a*	b*	pH	TSS (°Bx)
30	70	70	0	37.20	-9.78	21.21	5.2	1.90
			24	39.35	-6.34	24.46	5.1	5.10
			48	49.32	4.32	29.14	5.0	9.44
			72	51.19	9.04	30.37	4.9	12.69
		80	0	37.20	-9.78	21.21	5.2	1.90
			24	42.30	-1.84	27.82	5.0	7.94
			48	48.23	1.20	30.03	5.0	11.02
			72	52.98	10.98	32.84	4.9	13.68
		90	0	37.20	-9.78	21.21	5.2	1.90
			24	45.39	-4.02	27.82	5.0	8.97
			48	49.31	1.98	31.74	5.0	12.49
			72	53.84	11.79	33.94	4.8	14.24
	80	70	0	37.20	-9.78	21.21	5.2	1.90
			24	40.37	-5.03	27.50	5.0	7.94
			48	48.20	6.12	31.80	4.9	11.68
			72	53.92	10.17	32.10	4.8	13.38
		80	0	37.20	-9.78	21.21	5.2	1.90
			24	43.19	-4.68	28.20	5.0	8.90
			48	50.20	1.93	30.14	4.9	12.64
			72	54.82	11.48	33.18	4.8	14.82
		90	0	37.20	-9.78	21.21	5.2	1.90
			24	43.90	-3.09	29.58	5.0	9.97
			48	51.24	3.79	31.99	5.0	13.75
			72	56.03	12.79	34.38	4.7	15.40
	90	70	0	37.20	-9.78	21.21	5.2	1.90
			24	42.74	-4.21	24.80	5.0	8.90
			48	49.88	1.98	28.64	4.9	12.63
			72	55.96	11.93	33.20	4.9	14.24
		80	0	37.20	-9.78	21.21	5.2	1.90
			24	44.93	-3.10	26.91	5.0	10.38
			48	51.28	2.79	29.84	4.9	13.12
			72	56.12	13.21	34.60	4.8	15.37
		90	0	37.20	-9.78	21.21	5.2	1.90
			24	46.18	-3.10	29.10	5.0	11.24
			48	53.36	3.09	32.63	4.9	13.96
			72	57.27	14.17	36.39	4.7	16.10

These results are in agreement with the finding of Kulkarni *et al.*, 8; Soltani *et al.*, 12; Venkatram and Pandiarajan, 14.

The a* value of banana increased gradually from -9.78 to 9.04, 10.98, 11.79 when ripening period increased from 0 to 72 hours during ripening at 30°C temperature and 70% RH for the ethylene gas concentration 70, 80 and 90 ppm, respectively (Table 1). Similarly, during ripening at 30°C, the a* value of banana was found to be gradually increased

Table 2. Effect of different process parameters on quality of banana during ripening at 40°C.

Temp. °C	RH (%)	Ethylene concn. (ppm)	Ripening period (h)	L*	a*	b*	pH	TSS (°Bx)
40	70	70	0	37.20	-9.78	21.21	5.2	1.90
			24	42.00	-5.10	27.10	5.0	6.80
			48	54.20	5.30	32.50	4.9	11.89
			72	56.40	10.47	33.10	4.9	13.90
		80	0	37.20	-9.78	21.21	5.2	1.90
			24	44.10	-4.02	28.00	5.0	8.20
			48	52.00	2.27	32.08	4.9	13.20
			72	57.30	11.74	34.13	4.8	14.80
		90	0	37.20	-9.78	21.21	5.2	1.90
			24	44.72	-3.60	29.24	4.9	9.80
			48	52.30	2.88	33.20	4.9	14.80
			72	58.12	12.93	35.16	4.8	15.82
	80	70	0	37.20	-9.78	21.21	5.2	1.90
			24	42.90	-4.63	28.20	5.0	7.20
			48	56.10	6.20	33.10	4.9	12.10
			72	57.60	11.26	34.27	4.8	14.10
		80	0	37.20	-9.78	21.21	5.2	1.90
			24	44.97	-4.03	29.78	5.0	8.90
			48	52.90	3.21	32.95	5.0	13.80
			72	58.27	12.70	35.19	4.8	15.90
		90	0	37.20	-9.78	21.21	5.2	1.90
			24	45.60	-2.50	30.91	5.0	10.60
			48	53.40	4.71	34.24	4.9	15.50
			72	59.20	13.86	36.96	4.7	16.76
	90	70	0	37.20	-9.78	21.21	5.2	1.90
			24	43.87	-3.99	29.60	5.0	8.45
			48	53.39	3.14	34.10	4.9	13.30
			72	58.68	12.83	35.98	4.8	15.10
		80	0	37.20	-9.78	21.21	5.2	1.90
			24	45.71	-2.75	29.83	5.1	11.10
			48	53.89	4.10	33.50	5.0	14.40
			72	59.40	14.82	37.50	4.7	16.87
		90	0	37.20	-9.78	21.21	5.2	1.90
			24	49.64	-1.06	32.38	5.0	12.40
			48	54.20	5.82	35.82	4.8	16.50
			72	60.61	16.12	38.14	4.7	17.80

from -9.78 to 10.17, 11.48, 12. for 80% RH and from -9.78 to 11.93, 13.21, 14.17 for 90% RH when ripening period increased 0 to 72 hours for the ethylene gas concentration of 70, 80 and 90 ppm, respectively.

It can be observed from Table 2 that during ripening of banana at 40°C temperature and RH of 70%, the a* value of banana was found to increase gradually from -9.78 to 10.47, 11.74, 12.93 with increase in ripening period from 0 to 72 hours for

Table 3. Software generated optimized solutions for process variables.

Parameter	Goal	Lower limit	Upper limit	Predicted solution
Temp. °C	In the range	30	40	90
Ethylene Concn, ppm	In the range	70	90	90
Ripening period, h	In the range	24	72	72
Relative humidity	In the range	70	90	40
TSS, °Bx	maximum	1.90	17.80	17.68
pH	minimum	4.70	5.10	4.79
L* value	maximum	39.35	60.61	60.26
a value	maximum	-6.34	16.12	12.35
b value	maximum	24.46	38.14	37.73

the ethylene gas concentration 70, 80 and 90 ppm, respectively. Similarly, for 80 and 90 % RH at 40°C temperature, the a* value of banana was found to increase gradually from -9.78 to 11.26, 12.70, 13.86 and -9.78 to 12.83, 14.82, 16.12 as ripening period increased from 0 to 72 hours for the ethylene gas concentration of 70, 80 and 90 ppm, respectively. During ripening, the banana peel colour changed from dark green to bright yellow colour due to change in chlorophyll which gradually unmasked the carotenoid pigment present in unripe banana which leads increasing in a* value. These results are in agreement with the finding of Ahmed *et al.*, 1; Chen and Ramaswamy, 3 and Kulkarni *et al.*, 8 for banana ripening.

Table 1 clearly shows that during ripening at 30°C temperature and 70% RH, the b* value of banana increased gradually from 21.21 to 30.37, 32.84, 33.94 as period increased from 0 to 72 hours for the ethylene gas concentration 70, 80 and 90 ppm, respectively. Similarly, for other combinations of relative humidity at 30°C temperature, the b* value of banana was found to increase gradually from 21.21 to 32.10, 33.18, 34.38 for 80% RH and 21.21 to 33.20, 34.60, 36.39 for 90% RH with progress in ripening period 0 to 72 hours for the ethylene gas concentration of 70, 80 and 90 ppm, respectively.

It can be predicted from Table 2 that at 40°C temperature and 70% relative humidity, the b* value of banana increased gradually from 21.21 to 34.27, 34.13, 35.16 as ripening period progressed from 0 to 72 hr for the ethylene gas concentration 70, 80 and 90 ppm, respectively. Similarly, during ripening at temperature of 40°C, the b* value of banana was found to be gradually increased from 21.21 to 35.98, 35.19, 36.96 for 80% RH and 21.21 to 33.10, 37.50, 38.14 for 90% RH with increase in ripening period from 0 to 72 hours for the ethylene gas concentration of 70, 80 and 90 ppm, respectively. During ripening, the green dark colour of banana changed into yellow colour due to breakdown of chlorophyll in the peel. As yellowness of the banana peel increased which leads increasing in b* value. Similar results were reported by Chen and Ramaswamy, 3; Kulkarni *et al.*, 8 and Soltani *et al.*, 12.

The software generated optimum conditions of independent variables with the predicted values of responses is given in Table 3. The table shows that the best possible combination of temperature, RH and ethylene gas concentration for banana ripening was optimized as 40°C, 90% and 90 ppm with a ripening period of 72 hours. The optimized values of TSS, pH, L*, a* and b* were observed to be 17.68 %, 4.79, 60.26, 12.35 and 37.73, respectively for ripening of banana fruits after 72 hours of ripening at combination of temperature, RH and ethylene gas concentration of 40°C, 90% and 90 ppm which are very close to values of standard sample of ripen sample. The results are in agreement with the finding of Ahmed *et al.*, 1 and Venkatram and Pandiarajan, 14.

The ripening quality parameters *viz*., total soluble solid, pH, L* value, a value and b value of banana was found to be dependent on temperature, relative humidity, ethylene gas concentration and ripening period. The ripening of banana can be performed with the help of ethylene gas in a closed chamber within three days and if farmer wants to sell these bananas then it can be taken out after 48 hours of treatment for selling purposes.

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