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Experimental Study of the Effects of Convective Drying on Some Selected Vegetables

Samson A. Adeleye [a], Iyiola O. Oluwaleye [a] and Taiwo O. Oni [a*]

[a] Department of Mechanical Engineering, Faculty of Engineering, Ekiti State University, P.M.B. 5363, Ado-Ekiti, Nigeria.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Aim: This work gives the reports on experimental study of the effects of drying on some selected vegetables, namely fluted pumpkin (specimen I), spinach (specimen II), lettuce (specimen III), and waterleaf (specimen IV).

Methodology: The vegetable specimens were dried at regulated drying temperatures of 323K, 333K, and 343K, and the percentage amount of water, fat, crude fibre, ash, protein, and carbohydrate, as well as the fungi and bacteria counts in the vegetable specimens was determined at these temperatures.

Results: The results revealed that the amount of water in the vegetable specimens reached 0% earlier at the regulated drying temperature of 343K than at the other regulated drying temperatures. The results also indicated that the dried vegetable specimen II has highest fat content of 8.2%, the dried vegetable specimen III has highest crude fibre content of 14.5%, the dried vegetable specimen IV has highest ash content of 18.6%, the dried vegetable specimen I has highest protein content of 30.3%, and the dried vegetable s specimen III has highest carbohydrate content of 42.2% at the regulated drying temperature of 323K. The same trend of results was obtained for the regulated drying temperatures of 333K and 343K. Furthermore, the results showed that at the regulated drying temperature of 323K, the dried vegetable specimen III has the lowest bacteria counts of 4.3×10^7 CFU/g. The trend of result obtained for the regulated drying

**Corresponding author: Email: tooni1610@yahoo.com;*

temperatures of 333K and 343K is similar to that of the 323K. At the regulated drying temperature of 323K, the dried vegetable specimen II has the lowest bacteria counts of 1.7×10^7 CFU/g. The same trend of results was obtained for the regulated drying temperatures of 333K and 343K.
Conclusions: Drying has effects on the percentage amount of fat, crude fibre, ash, protein, and carbohydrate in the vegetable specimens. The microbial counts and the fungi counts decrease when the temperature increases. The present work can be applied in food engineering industries, and engineering in agriculture.

Keywords: Drying; temperature; vegetable; percentage amount.

1. INTRODUCTION

A vegetable is an herbaceous plant that can be eaten as part of a meal to keep man healthy [1]. If vegetables are not properly preserved, they will spoil and their nutritional qualities will depreciate. Refrigeration is one of the means of preservation of vegetables, but refrigeration is not reliable where there is no regular supply of power. According to Lewicki and Lenart [2], drying is a viable alternative mean of preservation of vegetables.

Drying of produce of agriculture such as grains, fruits, and vegetables with sun is a very common method because sun is available everywhere. Some of the factors affecting drying rate are velocity of wind, relative humidity, type of crops, solar radiation, and the mass per unit area of the products [3].

Moisture dehydration is one of the ancient systems of preserving agricultural products, like vegetables and fruits. This allows their better storage life, reduction of losses at a time of storage, and reduction in the cost of transportation [4]. Drying of vegetables can bring about improvement in palatability and digestibility of vegetables, and also brings about change of color, flavor, and appearance of the vegetable [5].

Drying is a process through which storage life of food is enhanced. It minimizes the moisture content of food products by weakening the microorganisms that causes deterioration [6]. It is a thermal process in which heat is supplied by hot air to the products to be dried and the water in the products is removed [7].

Various works on drying of agricultural products have been published in literature [7-21]. Despite this, there is yet to have a report on drying of agricultural products that specifies a regulated drying temperature. In this work, the effects of drying under different regulated drying temperatures on four different vegetable specimens are spotlighted. The present work can be applied in food industries, and engineering in agriculture.

2. METHODOLOGY

2.1 Materials

Experimental investigations were carried out on four vegetable specimens. The vegetables were bought in Oba's market in Otun-Ekiti, Nigeria. They were washed with water, cut into equal size of 5mm with a knife, and a digital beam balance was used to ensure that the cut specimens have equal mass of 10g. The English name and botanical name of the vegetable specimens are itemized in Table 1.

The pictures of the vegetable specimens are shown in Plate 1.

2.2 Basic Theoretical Equation

The percentage amount of water in the vegetable as drying progresses is calculated by considering the wet-basis water content, expressed by equation (1), adapted from Henderson et al. [22]:

$$\mathrm{WC} = \frac{\mathrm{m_{dv,t}} - \mathrm{m_{dv,T}}}{\mathrm{m_{fv}}} \times 100\% \tag{1}$$

where
WC = percentage amount of water in the vegetable specimen at a particular time of drying (%)
$\mathrm{m_{dv,t}}$ = mass of the vegetable specimen at a particular time of drying (g)
$\mathrm{m_{dv,T}}$ = mass of the vegetable specimen at the end of period of drying (g)
$\mathrm{m_{fv}}$ = mass of the fresh vegetable specimen before drying commences (g)

Table 1. Variety of the vegetable specimens

S/N	Vegetable specimens	English names	Botanical names
1	I	Fluted pumpkin	Telfaria occidentalis
2	II	African spinach	Amaranthu scruentus
3	III	Lettuce	Lactuca satuva
4	IV	Waterleaf	Talinum triangulare

Fluted pumpkin

African spinach

Lettuce

Waterleaf

Plate 1. Pictures of the vegetable specimens

2.3 Experimental Set-up

The dryer that was used to conduct the experiments was modified from the one used by Komolafe [23]. Its picture and schematic diagram are shown in Plate 2 and Fig. 1, respectively. The dryer consist of some components: The drying chamber was constructed with a galvanized-metal sheet of dimension 80.8 cm x 43.8 cm x 64.8 cm. The drying cage (inside the drying chamber) holds the vegetables. The dimensions of the drying cage are 72.0 cm x 35.0 cm x 3.6 cm. The placement of the drying cage inside the drying chamber is shown in Plate 3 , and it is shown schematically in Fig. 2. A thermostat is installed on the dryer to regulate the drying temperature. The fan forces air into the drying chamber. A heater which has three heating elements, each of which is 3,000 watts, is installed inside the dryer to supply heat to it. A 1-hp electric motor drives the pulleys.

2.4 Drying Procedure

Firstly, each of the vegetable specimens were collected, washed, and cut into size of 5mm and mass of 10g. A digital beam balance was the instrument used to measure the mass of the fresh vegetable. Then, the vegetables were loaded inside the cage of the drying chamber of the dryer, a thermostat was used to regulate the drying temperature of the dryer to 323K, 333K, and 343K to dry the vegetables, and the dryer was switched on. The period for the drying was 360 minutes. For each regulated temperature, the vegetables were removed from the dryer at interval of ten minutes after the commencement of drying, and a beam balance was used to measure the mass of the vegetable specimens. At the intervals of ten minutes up to the end of the 360-minute period of drying, the percentage amount of water in the vegetable specimens was determined by means of equation (1). The microbial load analysis and proximate analysis of the vegetables were conducted in a laboratory.

A flow diagram to explain the drying procedure is presented in Fig. 3.

3. RESULTS AND DISCUSSIONS

3.1 Percentage Amount of Water in the Vegetable Specimens

At various regulated drying temperatures of 323K, 333K, and 343K, the percentage amount of water in the vegetable specimens were taken at interval of ten minutes, and the results are depicted in Fig. 4 to Fig. 6 below. The percentage amount of water at the drying time of 0 minute is the initial value of moisture in the specimens.

For the regulated temperature of 323K (Fig. 4), the percentage amount of water in the fresh vegetable specimens I, II, III, and IV before the commencement of drying (that is, at drying time of 0 minute) is 81, 81, 94, and 92%, respectively. Ten minutes after that, the respective percentage amount of water has reduced to 76, 74, 84, and 87%, respectively. At the drying time of 270 minutes, percentage amount of water is 7, 13, 8, and 8% for the vegetable specimens I, II, III, and IV, respectively. It was observed that the percentage amount of water reached a value of 0% at drying time of 360, 360, 330, and 350 minutes for the vegetable specimens I, II, III, and

IV, respectively. This means that the vegetable specimens I, II, III, and IV dried completely at drying time of 360, 360, 330, and 350 minutes, respectively.

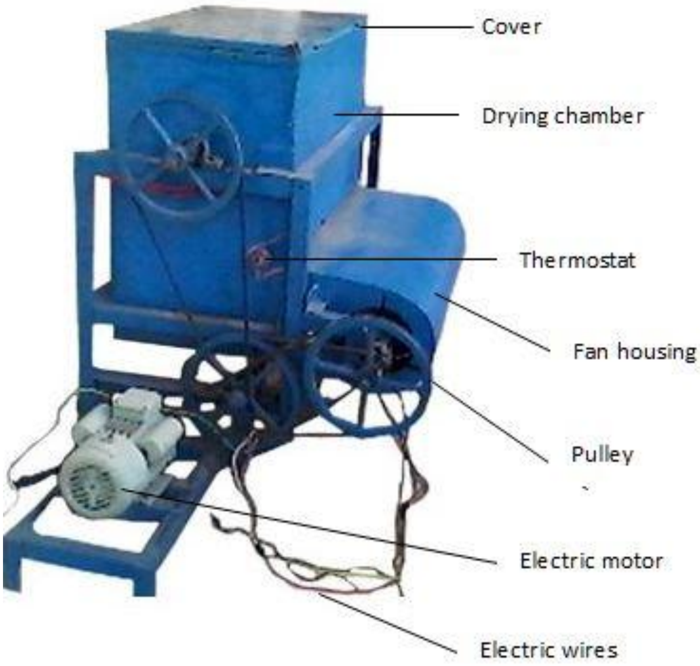

Plate 2. Picture of the dryer [Modified from [23]

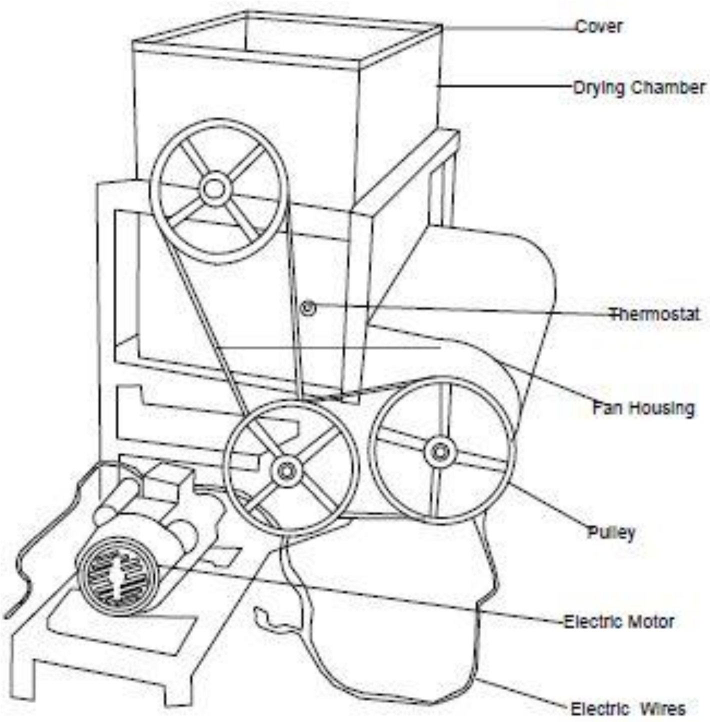

Fig. 1. Schematic diagram of the dryer

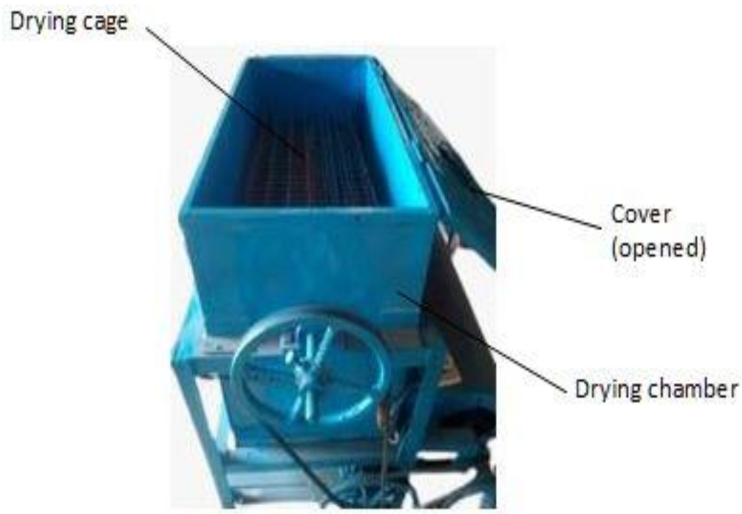

Plate 3. Picture showing the placement of the drying cage inside the drying chamber [Modified from [23]

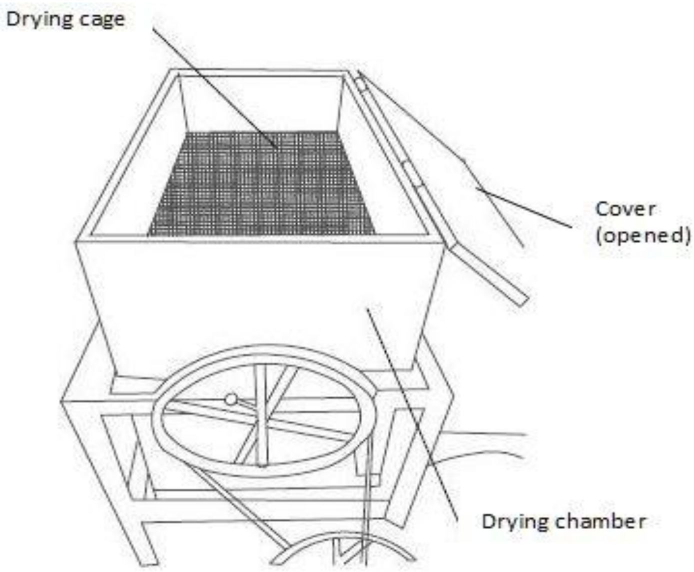

Fig. 2. Schematic diagram of the placement of the drying cage inside the drying chamber

In the case of the regulated temperature of 333K (Fig. 5), the percentage amount of water is 83, 83, 95, and 93% in the fresh vegetable specimens I, II, III, and IV before the commencement of drying, that is at drying time of 0 minute. Ten minutes after that, the percentage amount of water is 75, 76, 80, and 85% in the vegetable specimens I, II, III, and IV, respectively. The percentage amount of water in the vegetable specimens I, II, III, and IV is 7, 10, 5, and 8%, respectively at drying time of 270 minutes. The percentage amount of water is 0% in the vegetable specimens I, II, III, and IV at drying time of 350, 350, 330, and 340 minutes, respectively. This points out that it took a time of 350, 350, 330, and 340 minutes for the vegetable specimens I, II, III, and IV, respectively, to dry completely.

For the regulated temperature of 343K (Fig. 6), the percentage amount of water in the fresh vegetable specimens I, II, III, and IV (that is, at drying time of 0 minute) is 81, 81, 94, and, 92%, respectively. Ten minutes after that, the respective percentage amount of water has reduced to 74, 71, 80, and 85%, respectively. At drying time of 270 minutes, the percentage amount of water is 6, 9, 2, and 7% for the vegetable specimens I, II, III, and IV, respectively. It was observed that the percentage amount of water reaches a value of 0% at drying time of 340, 330, 300, and 350 minutes for the vegetable specimens I, II, III, and IV, respectively. This means that the vegetable specimens I, II, III, and IV completely dried at drying time of 340, 330, 300, and 350 minutes, respectively.

The percentage amount of water in the vegetable specimens is displayed in Appendix I to Appendix III. In the Appendices, the percentage amount of water at the drying time of 0 minute is the initial value of moisture in the specimens.

3.2 Proximate Analyses

Proximate analyses were carried out on fresh vegetable specimens and the vegetable specimens that were dried up to the end of the 360-minute drying period to know the effect of different regulated drying temperatures on percentage amount of fat, crude fibre, ash, protein, and carbohydrate in the vegetable specimens. The percentage amount of these contents in the fresh vegetable specimens and the dried vegetable specimens were compared.

As it can be seen in Fig. 7, for the regulated temperature of 323K, the percentage amount of fat, crude fibre, ash, protein, and carbohydrate in the fresh vegetable specimen I is 1.4, 2.0, 1.6, 7.4, and 7.1%, respectively. For the dried vegetable specimen I, these contents increase to 6.1, 8.3, 6.4, 30.3, and 29.9%, respectively. The percentage amount of fat, crude fibre, ash, protein, and carbohydrate in the fresh vegetable specimen II is 2.1, 2.5, 3.2, 1.0, and 12.2%, respectively. The amount of these contents increases to 8.2, 12.3, 16.4, 6.1, and 38.0%, respectively, in the dried vegetable specimen II. It can be seen that 0.7, 2.1, 2.2, 2.0, and 1.5% are the percentage amount of fat, crude fibre, ash, protein, and carbohydrate, respectively, in the fresh vegetable specimen III. These increase to 5.0, 14.5, 14.5, 16.3, and 42.2%, respectively, in the dried vegetable specimen III. The fresh vegetable specimen IV has the percentage amount of fat, crude fibre, ash, protein, and carbohydrate of 1.0, 1.1, 2.0, 2.5, and 3.3%, respectively. For the dried vegetable specimen IV, these values increase to 8.0, 10.0, 18.6, 20.3, and 34.6%, respectively.

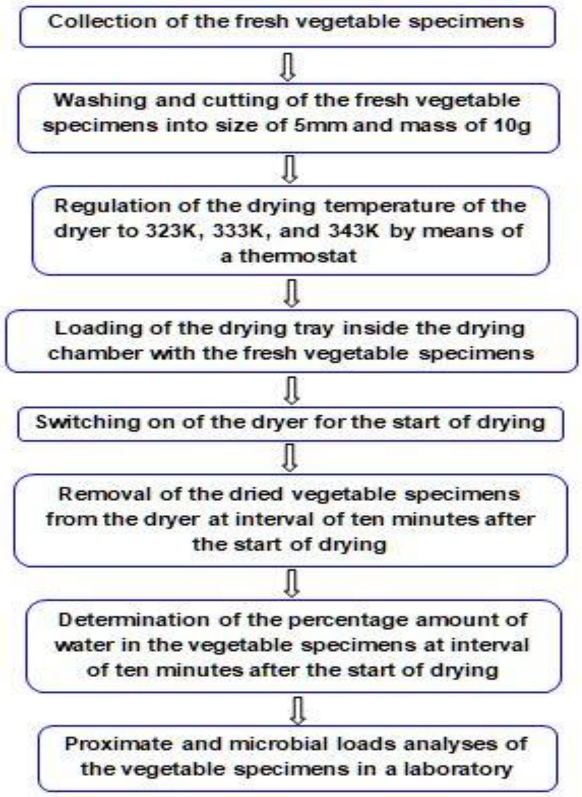

Fig. 3. A flow diagram to explain the drying procedure

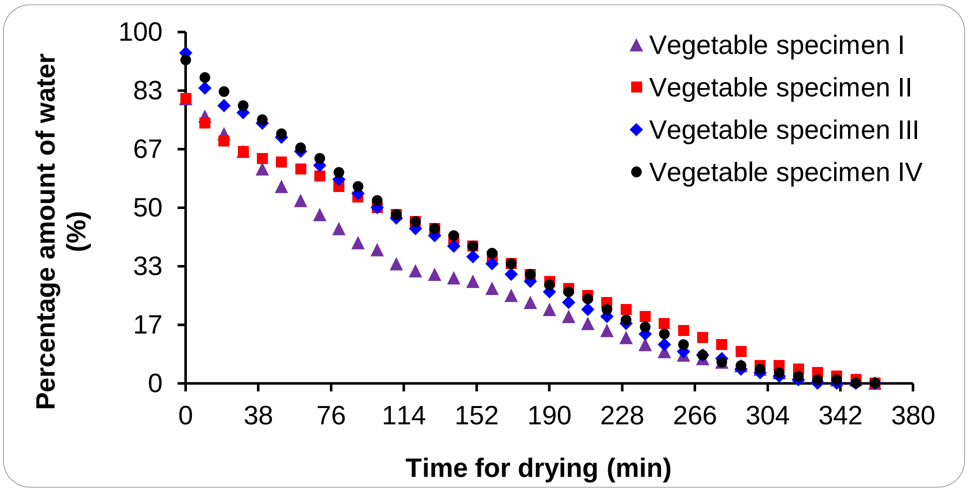

Fig. 4. Percentage amount of water (%) for drying time (min) at 323K regulated drying temperature

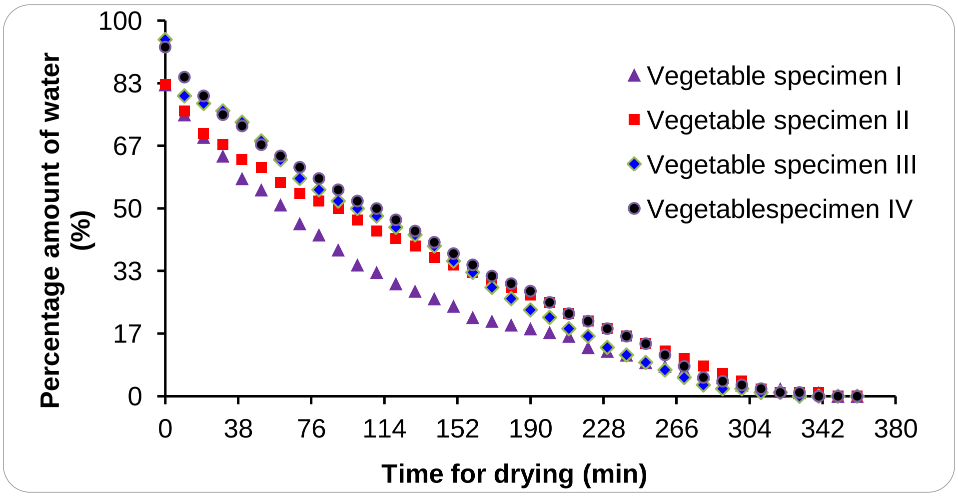

Fig. 5. Percentage amount of water (%) for drying time (min) at 333K regulated drying temperature

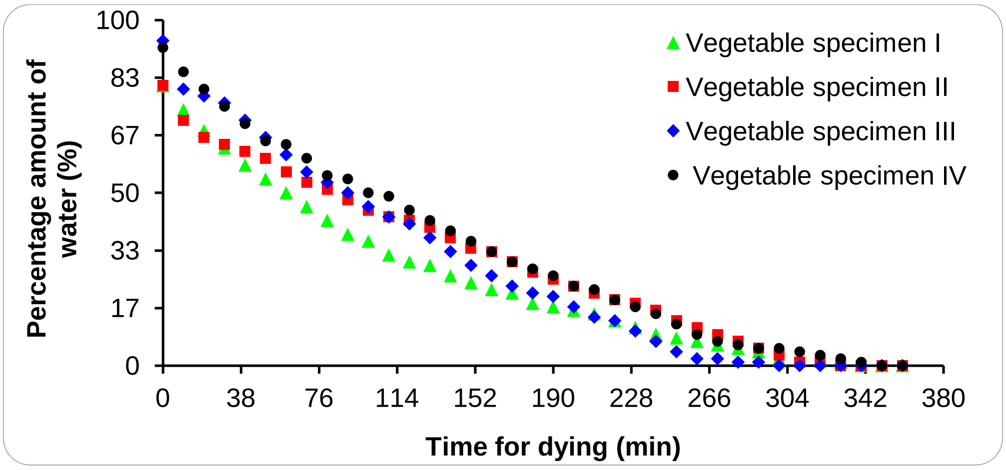

Fig. 6. Percentage amount of water (%) for drying time (min) at 343K regulated drying temperature

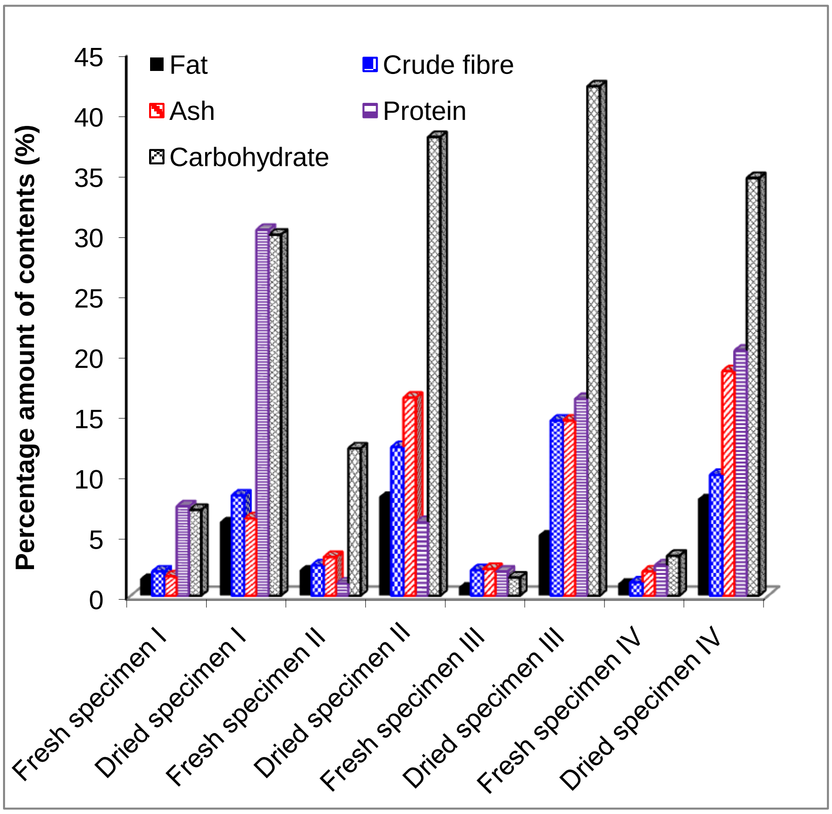

Fig. 7. Proximate analyses of the vegetable specimens at regulated drying temperature of 323K

Fig. 8. graphically presents the proximate analyses of the vegetable specimens at regulated temperature of 333K. It is evident in Fig. 6 that1.4, 2.0, 1.6, 7.4, and 7.1% are the percentage amount of fat, crude fibre, ash, protein, and carbohydrate, respectively, in the fresh vegetable specimen I. These increase to 6.1, 8.3, 6.4, 30.3, and 29.9%, respectively, in the dried vegetable specimen I. The percentage amount of fat, crude fibre, ash, protein, and carbohydrate in the fresh vegetable specimen II is 2.1, 2.5, 3.2, 1.0, and 12.2%, respectively. For the dried vegetable specimen II, these contents increase to 8.2, 12.4, 16.4, 16.2, and 38.0%, respectively. The fresh vegetable specimen III has the percentage amount of fat, crude fibre, ash, protein, and carbohydrate of 0.7%, 2.1%, 2.2%, 2.1%, and 1.4%, respectively. The dried vegetable specimen III increases the amount to 5.0, 14.6, 14.5, 16.4, and 42.0%, respectively. The percentage amount of fat, crude fibre, ash, protein, and carbohydrate in the fresh vegetable specimen IV is 1.0, 1.2, 2.0, 2.4, and 3.3%, respectively. The amount of these contents increases to 8.0, 10.1, 18.6, 20.3, and 33.4%, respectively, in the dried vegetable specimen IV.

Fig. 9 demonstrates that the percentage amount of fat, crude fibre, ash, protein, and carbohydrate in the fresh vegetable specimen I is 1.4%, 2.0%, 1.6%, 7.4%, and 7.1%, respectively. The amount of these contents increases to 6.1, 8.3, 6.6, 30.3, and 29.8%, respectively, in the dried vegetable specimen I. The percentage amount of fat, crude fibre, ash, protein, and carbohydrate in the fresh vegetable specimen II is 2.1, 2.5, 3.2, 1.0, and 12.2%, respectively. For the dried vegetable specimen II, these contents increase to 8.2, 12.5, 16.4, 6.2, and 37.9%, respectively. It is evident that 0.7, 2.1, 2.2, 2.0, and 1.5% are the percentage amount of fat, crude fibre, ash, protein, and carbohydrate, respectively, in the fresh vegetable specimen III. These increase to 5.0, 14.6, 14.5, 16.4, and 42.1%, respectively, in the dried vegetable specimen III. The fresh vegetable specimen IV has the percentage amount of fat, crude fibre, ash, protein, and carbohydrate of 1.0%, 1.2%, 2.0%, 2.4%, and 3.3%, respectively. For the dried vegetable specimen IV, these increase to 7.9, 10.2, 18.6, 20.4, and 34.4%, respectively.

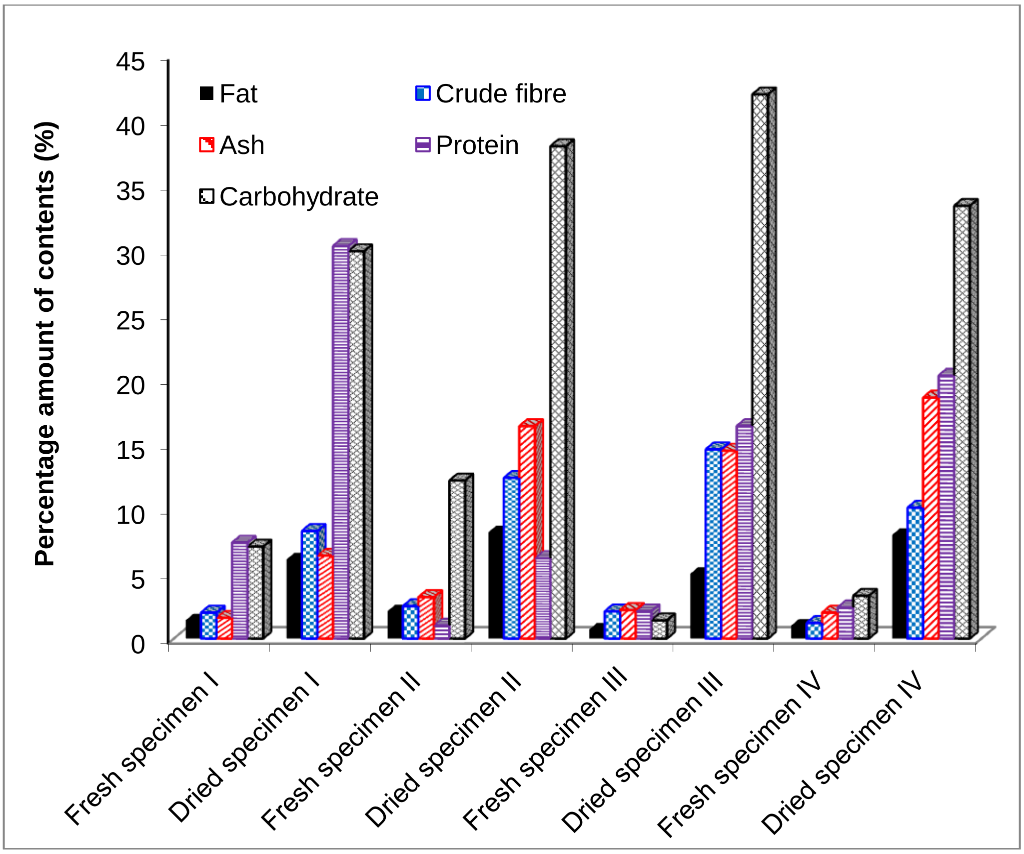

Fig. 8. Proximate analyses of the vegetable specimens at regulated drying temperature of 333K

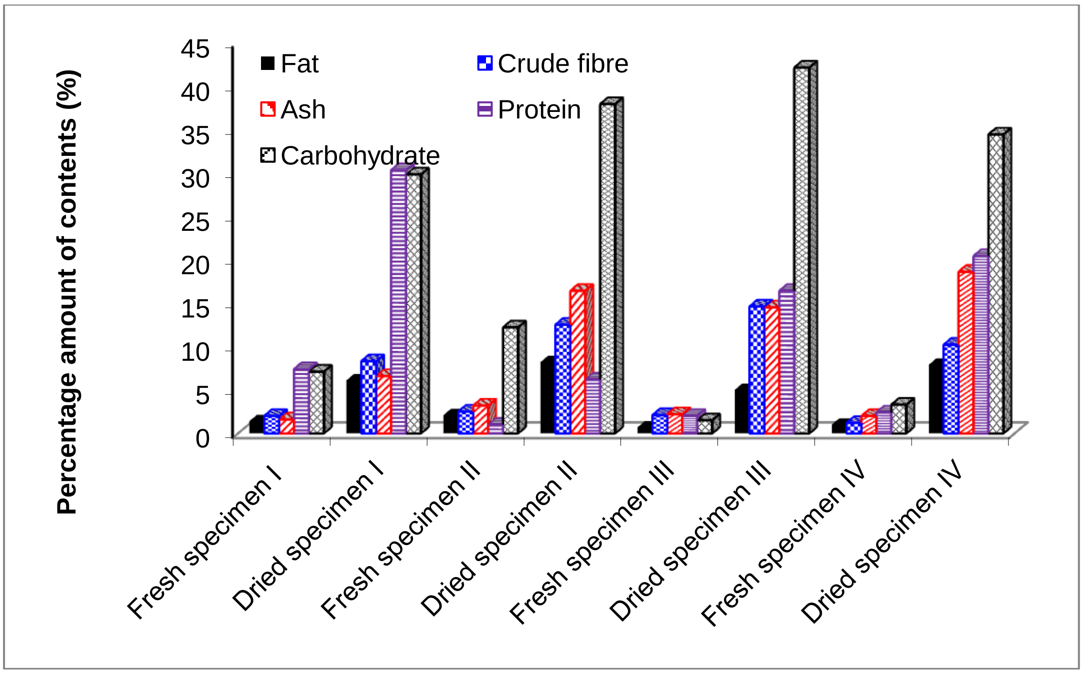

Fig. 9. Proximate analyses of the vegetable specimens at regulated drying temperature of 343K

3.3 Microbial Loads Analyses

The microbial loads analyses were conducted on fresh vegetable specimens and the vegetable specimens that were dried up to the end of the 360-minute drying period to know the bacterial counts and fungi counts in the vegetable specimens at the different regulated drying temperatures. These are shown in Fig. 10 and Fig. 11

The bacteria counts, as presented in Fig. 10, indicate that temperature affects microbial counts. The microbial counts decrease when the temperature increases. Fresh vegetables (that is, the ones that have not been dried) have bacteria of 8.1 x 10^7, 5.2 x 10^7, 5.5 x 10^7, and 6.7 x 10^7 CFU/g for the vegetable specimens I, II, III, and IV, respectively. When the vegetables were dried for 360 minutes at a regulated drying temperature of 323K, the bacteria counts in specimens I, II, III, and IV are 5.4 x 10^7, 4.5 x 10^7, 4.3 x 10^7, and 4.6 x 10^7 CFU/g, respectively. It was observed that when the vegetables were dried for 360 minutes at a regulated drying temperature of 333K, the bacteria counts in specimens I, II, III, and IV are 5.2 x 10^7, 4.0 x 10^7, 3.9 x 10^7, and 4.4 x 10^7 CFU/g, respectively. For the vegetable specimens that were dried for 360 minutes at a regulated drying temperature of 343K, the bacteria counts in specimens I, II, III, and IV are 4.9 x 10^7, 3.7 x 10^7, 3.5 x 10^7, and 4.1 x 10^7 CFU/g, respectively.

Fig. 11 shows the results of the fungi counts. It is revealed that the fungi counts decrease as the temperature increases. The fresh vegetables have fungi counts of 4.0 x 10^7, 2.7 x 10^7, 2.5 x 10^7, 3.1 x 10^7 CFU/g for the vegetable specimens I, II, III, and IV, respectively. At the

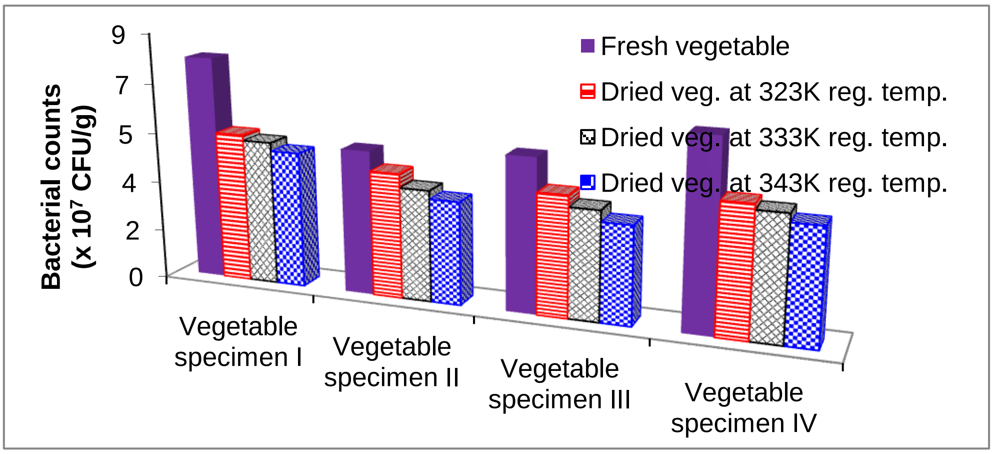

Fig. 10. Bacterial loads of the vegetable specimens at different regulated temperatures

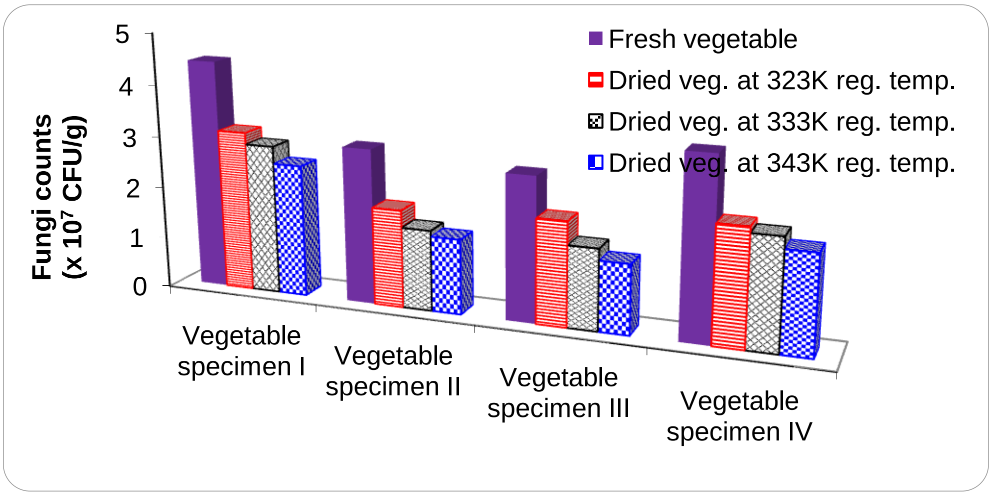

Fig. 11. Fungi loads of the vegetable specimens at different regulated temperatures

drying time of 360 minutes and a regulated drying temperature of 323K, the fungi counts in specimens I, II, III, and IV are 2.8 x 10^7, 1.7 x 10^7, 1.8 x 10^7, and 2.0 x10^7 CFU/g, respectively. At the regulated temperature of 333K and drying time of 360 minutes, the fungi counts in specimens I, II, III, and IV are 2.6 x 10^7, 1.4 x 10^7, 1.4 x 10^7, and 1.9 x 10^7 CFU/g, respectively. The fungi counts in the vegetable specimens I, II, III, and IV are 2.3 x 10^7, 1.3 x 10^7, 1.2 x 10^7, and1.7 x 10^7 CFU/g, respectively, at the drying time of 360 minutes and a regulated drying temperature of 343K.

4. CONCLUSIONS

A study was experimentally carried out on the effects of drying on four different specimens of vegetables, namely fluted pumpkin, spinach, lettuce, and waterleaf, referred to in this work as specimen I, specimen II, specimen III, and specimen IV, respectively.

A thermostat was used to regulate the drying temperature of the dryer that was used to dry the vegetable specimens. The vegetable specimens were dried at regulated drying temperatures of 323K, 333K, and 343K, and the effects of the drying temperature on the vegetable specimens were explored. Properties model and process model of drying are accurate for the vegetable specimens.

The results revealed that at the regulated drying temperature of 323K, the percentage amount of water reached a value of 0% at drying time of 360, 360, 330, and 350 minutes for the vegetable specimens I, II, III, and IV, respectively. The percentage amount of water is 0% in the vegetable specimens I, II, III, and IV at drying time of 350, 350, 330, and 340 minutes, respectively, at the regulated drying temperature of 333K. At the regulated drying temperature of 343K, the percentage amount of water reaches a value of 0% at drying time of 340, 330, 300, and 350 minutes for the vegetable specimens I, II, III, and IV, respectively.

Interestingly, it was observed that drying has effects on the percentage amount of fat, crude fibre, ash, protein, and carbohydrate in the vegetable specimens. The microbial counts and the fungi counts decrease when the temperature increases.

This work spotlights the effects of drying vegetables under different regulated drying temperatures. The output of the present work can be applied in food industries, and engineering in agriculture.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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APPENDIX

Appendix I. Percentage amount of water (%) for drying time (mins) at 323K regulated drying temperature

Drying time (mins)	Vegetable specimen I (%)	Vegetable specimen II (%)	Vegetable specimen III (%)	Vegetable specimen IV (%)
0	81	81	94	92
10	76	74	84	87
20	71	69	79	83
30	66	66	77	79
40	61	64	74	75
50	56	63	70	71
60	52	61	66	67
70	48	59	62	64
80	44	56	58	60
90	40	53	54	56
100	38	50	50	52
110	34	48	47	48
120	32	46	44	46
130	31	44	42	44
140	30	41	39	42
150	29	39	36	39
160	27	36	34	37
170	25	34	31	34
180	23	31	29	31
190	21	29	26	28
200	19	27	23	26
210	17	25	21	24
220	15	23	19	21
230	13	21	17	18
240	11	19	14	16
250	9	17	11	14
260	8	15	9	11
270	7	13	8	8
280	6	11	7	6
290	5	9	4	5
300	4	5	3	4
310	3	5	2	3
320	2	4	1	2
330	2	3	0	1
340	1	2	0	1
350	1	1	0	0
360	0	0	0	0

Appendix II. Percentage amount of water (%) for drying time (mins) at 333K regulated drying temperature

Drying time (mins)	Vegetable specimen I (%)	Vegetable specimen II (%)	Vegetable specimen III (%)	Vegetable specimen IV (%)
0	83	83	95	93
10	75	76	80	85
20	69	70	78	80
30	64	67	76	75
40	58	63	73	72
50	55	61	68	67
60	51	57	63	64
70	46	54	58	61
80	43	52	55	58
90	39	50	52	55
100	35	47	50	52
110	33	44	48	50
120	30	42	45	47
130	28	40	43	44
140	26	37	40	41
150	24	35	36	38
160	21	33	33	35
170	20	31	29	32
180	19	29	26	30
190	18	27	23	28
200	17	25	21	25
210	16	22	18	22
220	13	20	16	20
230	12	18	13	18
240	11	16	11	16
250	9	14	9	14
260	8	12	7	11
270	7	10	5	8
280	6	8	3	5
290	5	6	2	4
300	3	4	2	3
310	2	2	1	2
320	2	1	1	1
330	1	1	0	1
340	1	1	0	0
350	0	0	0	0
360	0	0	0	0

Appendix III. Percentage amount of water (%) for drying time (mins) at 343K regulated drying temperature

Drying time (mins)	Vegetable specimen I (%)	Vegetable specimen II (%)	Vegetable specimen III (%)	Vegetable specimen IV (%)
0	81	81	94	92
10	74	71	80	85
20	68	66	78	80
30	63	64	76	75
40	58	62	71	70
50	54	60	66	65
60	50	56	61	64
70	46	53	56	60
80	42	51	53	55
90	38	48	50	54
100	36	45	46	50
110	32	43	43	49
120	30	42	41	45
130	29	40	37	42
140	26	37	33	39
150	24	34	29	36
160	22	33	26	33
170	21	30	23	30
180	18	27	21	28
190	17	25	20	26
200	16	23	17	23
210	15	21	14	22
220	13	19	13	19
230	11	18	10	17
240	9	16	7	15
250	8	13	4	12
260	7	11	2	9
270	6	9	2	7
280	5	7	1	6
290	4	5	1	5
300	2	3	0	5
310	2	1	0	4
320	2	1	0	3
330	1	0	0	2
340	0	0	0	1
350	0	0	0	0
360	0	0	0	0

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