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OPTIMIZATION OF PRE-TREATMENTS FOR THE DEVELOPMENT OF DEHYDRATED WHOLE INDI LIME FRUITS (*Citrus aurantifolia* SWINGLE)

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ABSTRACT

Indi lime (*Citrus aurantifolia* Swingle), a GI-tagged citrus fruit of Vijayapura, Karnataka, is valued for its high juice content, characteristic aroma, rich vitamin C content and culinary and medicinal uses, but its high perishability limits its shelf life and utilization. The increasing demand for dehydrated lime products, especially in Gulf countries, provides scope for processing Indi lime into dehydarated whole lime. The present study aimed to develop a high-quality dehydrated whole-fruit product by evaluating the effects of blanching at three salt concentrations (0, 1 and 2.5%) and three blanching durations (1, 2 and 3 minutes). The treated fruits were dehydrated and evaluated for physicochemical and sensory characteristics. The pre-treatments significantly influenced moisture content, water activity, acidity, fibre, ash and sensory scores. Blanching in 2.5 per cent salt solution for 3 min recorded the lowest moisture content (6.44%) and water activity (0.26), highest ash content (4.83%), desirable dark colour, acidity (21.90%) and vitamin C content (11.64 mg/100 g). The treatment also recorded the highest overall acceptability score of 4.95 on a five-point hedonic scale and was found suitable for preparing quality dehydrated whole lime product, with scope for value addition and use in export markets.

***Key words*:** Indi lime, dehydration, blanching, salt treatment.

Introduction

Indi lime is a premium acid lime (*Citrus aurantifolia* Swingle) grown predominantly in Indi Taluk of Vijayapura district, Karnataka and is recognized with a Geographical Indication (GI) tag for its unique quality and geographical origin. The fruits have attractive green to yellow colour,thin peel, high juice content, pleasant aroma and balanced acidity, making them suitable for fresh consumption and processing (GI Registry, 2023). During 2021–22, acid lime cultivation covered an area of 10,777 ha in Vijayapura district, with a total production of 2,53,134 metric tonnes. Lime is a good source of ascorbic acid, antioxidants and other nutritionally important compounds. It is widely consumed as a fresh fruit and used for preparing beverages, pickles, squashes and other processed products. Although Indi lime has considerable commercial value, its short shelf life and seasonal production frequently lead to glut in the market and considerable fluctuations in fruit prices. During periods of glut, inadequate postharvest handling, storage and processing facilities may cause considerable losses and reduce returns to growers. Suitable preservation and value-addition methods are therefore needed to extend fruit utilization, reduce postharvest losses and improve its economic value. Dehydration is an effective method of fruit preservation because it reduces moisture content and water activity, thereby extending shelf life and reducing microbial spoilage. Dehydrated whole lime,

commonly known as black lime, is a traditional value-added product widely used in Middle Eastern cuisine and is also gaining demand in Gulf markets (Ezeonu *et al.*, 2001). During drying, whole lime develops a characteristic brown to black colour, shrivelled appearance and concentrated sour and aromatic flavour. It can also be further processed into powder. Product quality depends on pre-treatment and drying conditions, which influence moisture removal, colour, acidity, nutritional quality and sensory acceptability (Kadapatti, 2025). Therefore, the present investigation was carried out to optimize the blanching duration and salt concentration as pre-treatment conditions for producing dehydrated whole Indi lime fruits and to evaluate their influence on the physicochemical properties and sensory attributes of the final product.

Material and Methods

Fully matured, healthy and uniform-sized yellow-coloured Indi lime fruits (*Citrus aurantifolia* Swingle) were procured from the Agricultural Produce Market Committee (APMC), Bagalkot. The fruits were sorted to remove damaged and diseased fruits and washed thoroughly with clean water before processing.

The experiment was laid out in a 3 × 3 factorial completely randomized design (FCRD), comprising nine treatment combinations with three replications. The two experimental factors were blanching duration (1, 2 and 3 minutes) and salt concentration (0, 1 and 2.5%). The treatment combinations are presented in Table 1. The selected fruits were blanched in hot water containing the respective salt concentrations according to the treatments. After blanching for the specified duration, the fruits were immediately cooled in ice-cold water and drained to remove excess surface moisture. The pre-treated fruits were then dried in a hot-air oven at 70°C. Drying was continued until the fruits developed the desired brownish-black colour and characteristic dried texture. The dehydrated whole lime fruits were cooled to room temperature and packed in 200-gauge polypropylene bags for further analysis.

Weight loss was calculated from the difference between the initial and final fruit weight and expressed as percentage. Moisture content percentage was determined using a moisture analyser (Radwag MAC 50, Poland). Water activity was measured using a Novasina AG water activity meter (Switzerland). Titratable acidity was determined by titration against 0.1 N sodium hydroxide using phenolphthalein as an indicator and expressed as percentage citric acid. Ascorbic acid content was estimated by the 2,6-dichlorophenol indophenols dye titration method and expressed as (mg/100g) were determined according to standard AOAC (Anon., 1984). Crude fibre and ash contents were determined according to standard AOAC methods (Anon., 2000) and both expressed in percentage. Colour of the dehydrated whole lime samples was measured using a Hunter Lab colour meter (RT300 portable spectrometer, Tintometer Ltd., UK) and expressed as *L**, *a** and *b** values. Three observations were recorded for each sample and the mean value was used for statistical analysis. Sensory evaluation was carried out by a panel of 8–10 semi-trained judges. The samples were evaluated for colour and appearance, taste, aroma, shape retention and overall acceptability using a five-point descriptive scale (Amerine *et al.*, 1965). Data were analysed using ANOVA for a 3 × 3 factorial completely randomized design. Treatment means were compared using critical difference at 1 per cent significance level using WASP Version 2 (Jangam and Thali, 2010).

Table 1: Treatment combinations used for preparation of dehydrated whole lime.

A_1B_1	:	Blanching for1min in plain water
A_1B_2	:	Blanching for 1min in1% salt water
A_1B_3	:	Blanching for 1min in 2.5% salt water
A_2B_1	:	Blanching for 2 min in plain water
A_2B_2	:	Blanching for 2 min in 1% salt water
A_2B_3	:	Blanching for 2min in 2.5% salt water
A_3B_1	:	Blanching for 3 min in plain water
A_3B_2	:	Blanching for 3 min in1% salt water
A_3B_3	:	Blanching for 3 min in 2.5% salt water

Result and Discussion

The results obtained for the physicochemical, sensory and microbial characteristics of dehydrated whole lime as influenced by blanching duration and salt concentration are presented and discussed in the following sections.

Weight loss was not significantly affected by blanching duration, salt concentration and their interaction (Table 2). The overall mean was 84.72 per cent, with values ranging from 83.52 to 85.79 per cent. Moisture content (Table 2) was also not significantly affected by blanching duration, whereas salt concentration had a significant effect. B_1 recorded the highest moisture content (7.87%), followed by B_2 (7.37%) and B_3 (6.50%). The interaction was non-significant, although A_1B_1 recorded the highest numerical value (8.47%) and A_3B_3 the lowest (6.44%). The lower moisture content with salt treatment may be due to osmotic removal of water during pretreatment.

Water activity was significantly affected by blanching and salt concentration, while their interaction was non-significant (Table 2). Among blanching duration A_1

Table 2: Effect of different pre-treatment on weight loss, moisture content, water activity, titratable acidity, vitamin C content, total fiber, ash content of dehydrated whole lime.

Treatment	Weight loss (%)	Moisture content (%)	Water activity (aw)	Titratable Acidity (%)	Vitamin C (mg/100g)	Total fiber (%)	Ash content (%)
Factor I: Blanching duration							
A_1	84.39	7.50	0.31	22.47	13.01	8.54	3.75
A_2	84.54	7.17	0.27	22.21	12.77	8.24	4.09
A_3	85.23	7.07	0.27	22.03	12.56	7.83	4.32
Mean	**84.72**	**7.25**	**0.28**	**22.23**	**12.78**	**8.20**	**4.05**
S. Em±	**0.446**	**0.089**	**0.002**	**0.013**	**0.007**	**0.059**	**0.013**
CD at 1%	**NS**	**NS**	**0.008**	**0.053**	**0.028**	**0.239**	**0.053**
Factor II:Salt concentration							
B_1	84.06	7.87	0.31	21.59	12.66	7.92	3.67
B_2	84.95	7.37	0.27	22.38	12.79	8.16	3.94
B_3	85.14	6.5	0.27	22.73	12.90	8.53	4.55
Mean	**84.72**	**7.25**	**0.28**	**22.23**	**12.78**	**8.20**	**4.05**
S. Em±	**0.446**	**0.089**	**0.002**	**0.013**	**0.007**	**0.059**	**0.013**
CD at1%	**NS**	**0.361**	**0.008**	**0.053**	**0.028**	**0.239**	**0.053**
Interaction (A×B)							
A_1B_1	83.52	8.47	0.37	21.76	13.02	8.49	3.57
A_1B_2	84.76	7.44	0.28	22.71	13.01	8.51	3.67
A_1B_3	84.87	6.58	0.27	22.92	13.01	8.62	4.00
A_2B_1	84.02	7.65	0.28	21.56	12.57	7.82	3.60
A_2B_2	84.84	7.40	0.27	22.34	12.79	8.36	3.83
A_2B_3	84.57	6.46	0.27	22.72	12.95	8.54	4.83
A_3B_1	84.63	7.49	0.28	21.45	12.39	7.46	3.83
A_3B_2	85.26	7.29	0.27	22.08	12.56	7.61	4.32
A_3B_3	85.79	6.44	0.26	22.55	12.73	8.42	4.83
Mean	**84.72**	**7.25**	**0.28**	**22.23**	**12.78**	**8.20**	**4.05**
S.Em±	**0.772**	**0.154**	**0.004**	**0.022**	**0.012**	**0.102**	**0.022**
CD at 1%	**NS**	**NS**	**NS**	**0.089**	**NS**	**NS**	**0.089**

NS: Non Significant; **MAS**-Months after storage; A_1- Blanching for1 min; A_2- Blanching for2 min; A_3- Blanching for3 min; B_1- 0% Salt concentration; B_2- 1% Salt concentration; B_3- 2.5% Salt concentration

recorded the highest value (0.31) whereas, A_2 and A_3 recorded 0.27each. Among salt concentration, B_1 recorded the highest value (0.31), whereas B_2 and B_3 recorded 0.27 each. Longer blanching duration probably increased cell membrane permeability and tissue softening, facilitating rapid moisture diffusion during drying and resulting in lower residual moisture in the final product. Similar effects of pretreatment on moisture removal and water activity have been reported by Deepika and Sutar (2018) and Nasr *et al.*, (2021).

Acidity was significantly affected by blanching, salt concentration and their interaction (Table 2). Among blanching duration A_1 recorded the highest acidity (22.47%), while A_3 recorded the lowest (22.03%). Among salt concentration, B3 recorded the highest value (22.73%). At the interaction level, A_1B_3 recorded the highest acidity (22.92%) and A3B1 the lowest (21.45%). The reduction with prolonged blanching may be associated with leaching of soluble organic acids. Vitamin C content (Table 2) was significantly influenced by blanching and salt concentration whereas, their interaction was non-significant. Among blanching duration A_1 recorded the highest vitamin C content (13.01 mg/100 g), while A_3 recorded the lowest (12.56mg/100 g). Among salt treatments, B_3 recorded the highest value (12.90 mg/ 100g). The lower vitamin C content with prolonged blanching may be due to heat exposure and leaching. Similar observations were reported by El-Mesery *et al.*, (2022).

Total fibre was significantly affected by blanching and salt concentration, but their interaction was non-significant (Table 2). Among blanching duration A_1 recorded the highest fibre content (8.54%), whereas A_3 recorded the lowest (7.83%). Among salt concentrations B_3 recorded the highest value (8.53%). The reduction with prolonged blanching may be related to tissue

Table 3: Effect of different pre-treatment on Instrumental colour value (*L**, *a**and *b**) and organoleptic evaluation of dehydrated whole lime (5 point descriptive scale).

Treatment	Colour			Organoleptic evaluation				
	*L**	*a**	*b**	Colour	Shape retention	Aroma	Taste	Overall acceptability
Factor I: Blanching duration								
A_1	15.36	2.33	4.82	4.61	4.66	4.64	4.66	4.64
A_2	15.02	2.36	5.08	4.29	4.30	4.29	4.31	4.30
A_3	14.90	2.74	5.28	4.38	4.42	4.43	4.43	4.42
Mean	**15.09**	**2.48**	**5.06**	**4.43**	**4.46**	**4.46**	**4.47**	**4.45**
S. Em±	**0.007**	**0.182**	**0.198**	**0.007**	**0.019**	**0.019**	**0.006**	**0.005**
CD at 1%	**0.028**	**NS**	**NS**	**0.028**	**0.077**	**0.077**	**0.024**	**0.02**
Factor II:Salt concentration								
B_1	15.40	2.42	5.12	4.03	4.06	4.06	4.07	4.06
B_2	15.12	2.34	4.86	4.41	4.42	4.41	4.23	4.42
B_3	14.77	2.67	5.21	4.83	4.90	4.90	4.91	4.88
Mean	**15.10**	**2.48**	**5.06**	**4.43**	**4.46**	**4.46**	**4.47**	**4.45**
S. Em±	**0.007**	**0.182**	**0.198**	**0.007**	**0.019**	**0.019**	**0.006**	**0.005**
CD at1%	**0.028**	**NS**	**0.803**	**0.028**	**0.077**	**0.077**	**0.024**	**0.02**
Interaction (A×B)								
A_1B_1	15.49	2.30	6.01	4.33	4.37	4.97	4.37	4.35
A_1B_2	15.47	1.83	4.79	4.63	4.63	4.33	4.63	4.63
A_1B_3	15.12	2.86	3.67	4.87	4.97	4.63	4.99	4.95
A_2B_1	15.46	2.03	4.71	3.95	3.97	3.97	3.99	3.97
A_2B_2	14.87	2.45	4.77	4.15	4.17	4.13	4.17	4.16
A_2B_3	14.74	2.60	5.77	4.77	4.77	4.77	4.77	4.77
A_3B_1	15.25	2.93	4.65	3.83	3.83	3.87	3.85	3.85
A_3B_2	15.02	2.74	5.01	4.45	4.47	4.47	4.47	4.46
A_3B_3	14.44	2.55	6.18	4.87	4.97	4.97	4.98	4.95
Mean	**15.10**	**2.48**	**5.06**	**4.43**	**4.46**	**4.46**	**4.47**	**4.45**
S.Em±	**0.012**	**0.154**	**0.343**	**0.012**	**0.033**	**0.033**	**0.011**	**0.008**
CD at 1%	**0.049**	**NS**	**NS**	**0.049**	**NS**	**NS**	**0.045**	**0.032**

NS: Non Significant; **MAS**-Months after storage; A_1- Blanching for1 min; A_2- Blanching for2 min; A_3- Blanching for3 min; B_1- 0% Salt concentration; B_2- 1% Salt concentration; B_3- 2.5% Salt concentration

softening and loss of soluble components. Ash content (Table 2) was significantly affected by blanching, salt concentration and their interaction. A_3 recorded the highest ash content (4.32%) among blanching duration whereas, B_3 recorded the highest value among salt concentration (4.55%). At the interaction level, A_2B_3 and A_3B_3 recorded the highest ash content (4.83%) each, while A_1B_1 recorded the lowest (3.57%). The increase in ash may be associated with salt contribution and concentration of mineral constituents during dehydration. Similar changes have been reported by Gonzalez-Centeno *et al.,* (2015) and Mrad *et al.,* (2012).

The *L** value was significantly affected by blanching, salt concentration and their interaction (Table 3). A_1 recorded the highest *L** value (15.36), while A_3 recorded the lowest (14.90) among blanching duration. Among salt concentration, B_1 recorded the highest value (15.40) and B_3 recored the lowest (14.77). A_3B_3 recorded the lowest *L** value (14.44), indicating a darker product, whereas A_1B_1 recorded the highest (15.49). The *a** value was not significantly affected by blanching, salt concentration and their interaction. The *b** value was not significantly affected by blanching duration and interaction effects whereas, salt concentration had a significant effect, with B_3 recording the highest numerical value (5.21). The colour changes may be related to moisture removal and browning during dehydration. Similar changes have been reported by Darvishi *et al.,* (2014).

Blanching and salt concentration significantly affected colour, shape retention, aroma, taste and overall acceptability (Table 3). A1recorded the highest scores for colour (4.61), shape retention (4.66), aroma (4.64), taste (4.66) and overall acceptability (4.64) among blanching duration. Among salt treatments, B_3 recorded the highest scores for colour (4.83), shape retention (4.90), aroma (4.90), taste (4.91) and overall acceptability (4.88).

The interaction significantly affected colour, taste and overall acceptability, but not shape retention and aroma. For colour, A_1B_3 and A_3B_3 recorded the highest score for colour (4.87 each), while taste scores were highest in A_1B_3 (4.99) and A_3B_3 (4.98). Overall acceptability was highest in $A_1B_3$and A_3B_3 (4.95 each), followed by A_2B_3 (4.77) whereas, A_3B_1recorded the lowest score (3.85). The higher sensory acceptability of the treated fruits may be attributed to the combined effect of blanching and salt pretreatment, which promoted uniform colour development, reduced excessive shrinkage, improved flavour retention and maintained desirable texture during dehydration. Similar findings were reported by Prajapati *et al*., (2011) in dried aonla shreds, where blanching and pretreatment improved flavour, nutrient retention and overall acceptability of the dried product. Chandan *et al.*, (2024) also reported improved sensory quality in dehydrated lime products following suitable pretreatment and drying conditions.

Conclusion

Based on the physicochemical and sensory evaluation, blanching Indi lime fruits in a 2.5 per cent salt solution for 3 minutes was found to be the most effective pre-treatment for producing high-quality dehydrated whole lime fruits (black lime). The product exhibited a low moisture content (6.44%), water activity (0.26), ash content (4.83%), darker colour (*L** values 14.44) and the highest overall acceptability score (4.95 out of 5.00), indicating its potential for developing a value-added, shelf-stable product from Indi lime.

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