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# Development of shelf stable intermediate moisture carrot (*Daucus carota*) shreds using radiation as hurdle technology

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**Abstract**

Carrot (*Daucus carota*) is highly perishable and difficult to preserve fresh for long periods at ambient temperature and humidity. Shelf-stable intermediate moisture (IM) carrot shreds were developed based on 'hurdle technology' [HT] which included the combination of the factors like drying by two methods - Infrared drying (IR) / Tray drying (TD) to reduce water activity [$a_w$] to 0.6, pre-treatments and packaging. The product was stored in 400 gauge polyethene and treated with low doses of gamma radiation 0.5 kGy as a major hurdle technology and observed for shelf life stability at ambient conditions (30$^o$C and 65% RH). Infra red dried vegetables treated with gamma radiation (IRR) were found to be stable up to 6 months without substantial loss of flavor, taste, colour and texture than the other treatments. IRR yielded IM carrot shreds with improved rehydration potential, appearance and with the nutrient retention up to 52% of β-carotene, 59.8% of total carotenoids and 25.3% of vitamin C more than the tray dried IM carrot shreds. The product was microbiologically safe throughout the study. Infrared drying using radiation as hurdle technology could be suggested as a potential method for obtaining high quality IM products with optimum sensory, microbial and nutritional quality.



## Introduction

Carrot (*Daucus carota*) is an important vegetable, which has high nutritional value and utility. Carrot belongs to the family *Umbelli ferae*, genus *Daucus*, species *Carota*, and is one of the important root crops cultivated throughout the world for its fleshy edible roots. It is used for human consumption as well as for animal feed. Apart from having a great taste, carrot is also a rich source of essential vitamins and minerals. Carrots are highly nutritious as they contain appreciable amount of vitamins B1, B2, B6, and B12 and beta-carotene (Kalra *et al*., 1987). Cut or grated carrots represent an important component of culinary preparation. The color of the carrot tissue makes an essential contribution to an attractive appearance, which contributes a psychological appeal to the consumer. Loss of carotenoid resulting in surface discoloration of peeled carrots during storage affects the product quality and limits storage life.

Intermediate moisture (IM) fruits and vegetables have an advantage over traditionally dried ones, where instead of removing most of the water, just enough water is removed, or bound through the addition of humectants to retard microbial growth (Jayaraman *et al*., 1978; Jayaraman, 1995). However, IM foods have not achieved the expected consumer acceptance because of poor palatability caused by the high concentration of humectants and the high requirement for antimicrobial additives to maintain their stability. With the introduction of the hurdle technology (HT) concept (Leistner, 1978; Leistner, 1992) there is now a worldwide interest in HT foods based on the combination of preservation using two or more methods, none of which is individually sufficient to prevent microbial spoilage. HT enables the development and stabilization of Intermediate-moisture products storable at ambient conditions with partial processing and less energy input. Accordingly, partially dehydrated grated carrots were developed by HT and assessed for shelf stability at ambient temperatures. With the increased demand

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for fresh-like quality, processors have turned toward Intermediate-moisture products that are more stable than fresh products and use mild preservation techniques. Radiation processing is being used as preservation method for food commodities and is increasingly finding new applications (Diehl, 1990). This has proved to be one of the very effective alternatives for ensuring microbial quality and safety of minimally processed fruits and vegetables and is also recommended for processed fruits and vegetables (Brendan *et al*., 2004). However, very few reports exist on the use of radiation processing for enhancing shelf life of processed fruits and vegetables.

The objective of the present study was to standardize protocols for developing shelf stable Intermediate moisture carrot shreds with optimum sensory, microbial and nutritional quality using combined hurdles like different pre-treatments, drying methods, packaging material, moisture content, and gamma radiation processing.

## Materials and Methods

### Materials

Fresh carrots were procured from the local market and were then washed thoroughly with potable water, peeled, drained and grated using a food processor. The grated carrot shreds were subjected to various pretreatments.

*Standardization of pretreatments for preparation of IM carrot*

To select optimum pretreatment for processing of IM carrot five methods were employed. The first method was without any pre-treatment (Control) in which fresh carrot shreds were dried as it is. In second method (Cold water dip) carrot shreds were soaked in water containing 2% of sugar for 30 min at room temperature, removed, drained and dried. In third method (Blanching) where carrot shreds were blanched in hot water at 85˚C for 3-5 min to which 2% of sugar was added, removed, drained and dried. (For blanching, vegetables were tied in a muslin cloth and then dipped in the blanching solution). In fourth method (Partial drying) carrot shreds were partially dried (up to 50% of initial moisture content) and were soaked in sodium chloride solution which was prepared by dissolving sodium chloride, which is equivalent to 4 percent of partially dried product weight. Only minimum quantity of water was used to dissolve sodium chloride. In this solution the semi dried vegetables were allowed to stand for 15 to 30 min and kept for drying. In the fifth pre-treatment method (Combination of treatments) combination of cold water dip, blanching and partial drying were applied.

*Standardization of optimum drying conditions for IM products*

IM carrot shreds were processed using hot-air and infrared drying methods. To standardize the optimum drying time and temperature of each drier the carrot shreds were kept in Tray drier (TD) for drying at $80^0$C for first 1hr and at $60^0$C thereafter, where as in Infra red drier (IR) the carrot shreds were kept at $60^0$C till the desired moisture level (~ 30%) attained.

*Standardization of the packaging material for storage of IM products*

The standardized IM products were packed in 200, 400 gauge polythene bags and in aluminum foil cups with cling wrap and stored at ambient temperature $30^0$C-$35^0$C, RH 67% and low temperature$14^0$C - with RH 96 %.

*Standardization of radiation doses to be used for preparing IM products*

***Radiation treatment***

After giving the optimum pretreatments identified, the carrots were dried in Infra red drier and tray drier to 30-40% moisture content. These intermediate moisture carrots were packed in polythene bags, sealed and subjected to different levels of radiation doses of 0.25, 0.50, 0.75, 1.00 kGy, and stored at both ambient ($30^0$C-$35^0$C) and low temperatures ($14^0$C) along with control (without radiation). Shelf life of the products was analyzed at 0, 30, 60, 90, 120, 150 and 180 days of storage.

*Experimental design and treatment for shelf life studies*

The preparation of IM carrot in the following treatments were designed to ascertain the effect of shelf stability with optimal organoleptic quality. Treatment 1 Tray dried (TD), Treatment 2 Tray dried and radiated (TDR), Treatment 3 Infra red dried (IR), Treatment 4 Infra red dried and radiated (IRR). Standardized IM carrot shreds were analyzed for nutritional, microbiological and acceptability changes at an interval of 0, 30, 60, 90, 120, 150 and 180 days of storage period. Parameters assessed were as follows.

*Physical properties*

Hunter lab Colour spectrometer was used for colour estimation.The most common technique to assess the colour is by colorimetry. There are several colour scales in which the surface colour can be represented. The 3-dimensional scale L*, a* and b* is used where L* is the lightness coefficient, ranging from 0 (black) to 100 (white) on a vertical axis. The a* is purple-red (positive a* value) and blue-green (negative a* value) on a horizontal axis. A second horizontal axis is b* that represents yellow (positive b* value) or blue (negative b* value) colour (McGuire, 1992).

Physiological loss of weight was estimated by recording initial and subsequent weights during storage at regular intervals. Rehydration ratio was recorded as ratio of the weight of dehydrated sample to the weight of rehydrated sample and per cent of loss in weight was also computed (Ranganna, 1986).

*Chemical properties*

Moisture was estimated by AOAC, 1990. Total and beta carotenes were estimated by Spectro photo meter method (Zakaria *et al*., 1979). Vitamin C and acidity were estimated by titration method (Ranganna, 1986).

*Microbial properties*

For estimating viable bacterial, yeast and mould count dilution plate method was followed. For bacterial estimation, plate count agar was used and for yeast and mould potato dextrose agar was used (Krishnakumar *et al*., 2006).

*Organoleptic properties*

The organoleptic scoring was done by a panel of 10 members in the sensory evaluation laboratory using a score card developed for IM carrot evaluation purpose. A five point hedonic scale was used to evaluate (Peryam, 1957) the results and expressed as mean scores by taking average of all the replicates.

*Statistical analysis*

All the experiments were repeated three times and data obtained was statistically analyzed using Analysis of Variance ANOVA (Snecdor *et al*., 1983) two factor with replications to assess the significant difference at 0.05 % and 0.01% level using AGRES software. The effects of treatments between and within were compared. Once the product was spoilt that treatment was eliminated from analysis and only other three treatments were considered for two factor analysis.

## Results

*Pretreatment*

The optimum pretreatment was selected based on Rehydration ratio, Organoleptic evaluation including taste, flavor, colour, texture, appearance, and overall acceptability. Among all the pretreatments control scored higher sensory scores and hot blanching scored least for all attributes followed by cold water dip.

*Drying time and temperature*

Optimum drying conditions for different drying modes were established with respect to time, temperature based on desired moisture content, colour and texture. It was found that the required conditions were attained for infra red drier at $60^0$C temperature, 45 min of drying time where as for tray drier it was $80^0$C and 4 hours of drying time.

Table 1. Effect of drying, radiation and packing on shelf life and physical organoleptic quality of IM carrot stored at ambient temperature

| S.no | Parameters | *TD | | *TDR | | *IR | | *IRR | |
|---|---|---|---|---|---|---|---|---|---|
| A | Shelf life | '0' day | Three months | 0 day | Four months | '0' day | four months | '0' day | six months |
| 1 | Moisture | 27.8 | 24.5(11.8%) | 27.8 | 23.6(15.1%) | 26.6 | 24(9.8%) | 26.6 | 24(9.8%) |
| 2 | Average PLW | | 4.3 | | 5.6 | | 2.6 | | 1.2 |
| 3 | Rehydration Ratio | 6.2 | 3.3(53.2%) | 7.3 | 3.17(43.4%) | 7.53 | 6.03(80.1%) | 8.0 | 6.0(75%) |
| B | Sensory Scores | | | | | | | | |
| i | Taste | 4.2±0.5 | 2.56±0.6 | 4.3±0.7 | 1.8±0.7 | 4.5±0.2 | 3.0±0.3 | 4.8±0.1 | 2.5±0.2 |
| ii | Flavour | 4.2±0.5 | 2.92±0.5 | 4.4±0.6 | 1.5±0.5 | 4. 6±0.2 | 3.0±0.3 | 4.7±0.2 | 2.4±0.1 |
| iii | Texture | 4.0±0.3 | 2.33±0.2 | 4.6±0.5 | 1.2±0.4 | 4.9±0.3 | 3.2±0.5 | 4.8±0.1 | 3.0±0.5 |
| iv | Colour | 4.3±0.7 | 2.3±0.8 | 4.7±0.7 | 1.1±0.2 | 4.9±0.1 | 3.5±0.6 | 4.9±0.2 | 3.2±0.2 |
| v | OA | 4.2±0.4 | 2.16±0.9 | 4.4±0.2 | 1.5±0.3 | 4.8±0.2 | 3.0±0.2 | 4.9±0.1 | 3.1±0.3 |
| C | Colour values | | | | | | | | |
| .i | L* | 28.9±3 | 55.5±4 | 28.9±4 | 64.4±5 | 28.9±2 | 36.7±3 | 29.0±0.1 | 47.7±0.1 |
| ii | a* | 26.4±2 | 19.9±4 | 26.4±2 | 18.6±3 | 26.4±1 | 28.2±3 | 26.4±0.2 | 24.3±0.1 |
| iii | b* | 18.0±4 | 28.2±5 | 18.0±2 | 30.9±1 | 18.0±2 | 18.6±1 | 18.0±0.3 | 16.9±0.2 |

Note: Fig in parenthesis indicate Per cent change over initial value
Values are mean ± standard deviation of three determinations
[1]TD - Tray dried
[2]TDR - Tray dried and radiated
[3]IR - Treatment 3 Infra red dried
[4]IRR - Treatment 4 Infra red dried and radiated

Table 2. Effect of drying and radiation on nutritional quality of IM carrot stored at ambient temperature

| Percent of acidity | | | | | Vitamin 'C' mg/100g | | | | β carotene µg/100g | | | | Total carotenoids µg/100g | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Storage period | TD | TDR | IR | IRR | TD | TDR | IR | IRR | TD | TDR | IR | IRR | TD | TDR | IR | IRR |
| fresh | 0.13 | 0.13 | 0.13 | 0.13 | 18.4 | 18.4 | 18.4 | 18.4 | 210 | 210 | 210 | 210 | 2103 | 2103 | 2103 | 2103 |
| 0day | 0.96 | 0.96 | 0.13 | 0.13 | 10.4 (56.2) | 10.4 (56.2) | 12.5 (68.1) | 12.5 (68.1) | 783.2 (*3.7 times) | 783 (*3.7 times) | 960 (*4.6 times) | 960 (*4.6 times) | 8843 (*4.2 times) | 8843 (*4.2 times) | 9875 (*4.7 times) | 9875 (*4.7 times) |
| 1m | 1.22 | 1.09 | 1.15 | 1.20 | 8.4 | 7.1 | 11.5 | 11.0 | 720.6 | 713 | 931 | 921 | 8047 | 7765 | 9579 | 9529 |
| 2m | 1.28 | 1.08 | 1.28 | 1.15 | 6.3 | 5.4 | 9.9 | 9.9 | 626.6 | 556 | 902 | 892 | 6986 | 6840 | 9381 | 9233 |
| 3m | 1.40 | 1.22 | 1.34 | 0.96 | 3.4 (32.6) | 3.2 | 7.7 | 6.2 | 548.2 (69.9) | 423 | 768 | 835 | 6278 (71) | 6108 | 8690 | 8789 |
| 4m | discarded | 0.96 | 1.34 | 0.83 | discarded | 1.25 (11.9) | 6.5 (46.3) | 5.6 | discarded | 430.8 (55) | 663.1 (69.1) | 777 | discarded | 5809 (65.7) | 6715 (68) | 7900 |
| 5m | | discarded | discarded | 0.77 | | discarded | discarded | 4.2 | | Discarded | discarded | 72 | | discarded | discarded | 6922 |
| 6m | | | | 0.77 | | | | 3.1 (25.3) | | | | 499 (52) | | | | 5907 (59.8) |

Note: Fig in parenthesis indicate per cent change over initial value
*Indicates Increase of nutrient on different drying methods
[1]TD - Tray dried [2]TDR - Tray dried and radiated [3]IR - Infra red dried [4]IRR - Infra red dried and radiated

Table 3. Effect of drying and radiation on microbial quality of IM carrot stored at ambient temperature

| storage | Total Bacterial Count (log cfu/gm) | | | | Total Microbial Count (log cfu/gm) | | | |
|---|---|---|---|---|---|---|---|---|
| period | TD | TDR | IR | IRR | TD | TDR | IR | IRR |
| 0day | nvc | nvc | nvc | nvc | nvc | nvc | nvc | nvc |
| 1m | 1.12 | 1 | 1.2 | 0.62 | 1.1 | 1.2 | 1.1 | 0.62 |
| 2m | 1.34 | 1.2 | 1.3 | 0.83 | 1.2 | 1.5 | 1.2 | 0.83 |
| 3m | 2.1 | 1.5 | 1.4 | 1.2 | 2.08 | 1.6 | 1.31 | 1.1 |
| 4m | discarded | 1.7 | 1.72 | 1.5 | discarded | 1.9 | 1.9 | 1.3 |
| 5m | | discarded | discarded | 1.6 | | | discarded | 1.6 |
| 6m | | | | 1.7 | | | | 1.9 |

nvc: non viable count
*TD - Tray dried *TDR - Tray dried and radiated *IR - Infra red dried *IRR - Infra red dried and radiated

*Packing material for storage of IM products*

Moisture content, physiological loss in weight (PLW), fungal growth was taken as base to evaluate the quality of packing material. The results showed that in aluminum foil cups with cling wrap had 50% of moisture loss with in the first month though they retained more natural texture and colour where as samples packed in polyethylene bags retained 68% to 73% of moisture even after three months of storage and showed lower physiological loss in weight. Moisture retention levels of 400 gauge polyethene bags were found to be best followed by 200 gauge bags.

*Radiation dose*

The parameters used to assess the most suitable radiation dose are physical parameters such as moisture content, PLW, colour, rehydration ratio, fungal growth and organoleptic evaluation such as taste, flavor, colour, texture, appearance, and overall acceptability. Among the radiation treatments, 0.25 kGy dosage recorded lower PLW compared to other doses. However, considering all parameters, dosage of 0.25 and 0.5 kGy were considered best.

With the data obtained, the protocols to be used for preparation of IM carrot have been standardized with respect to pretreatment, drying time, temperature, packing material and optimum dose of radiation to be used.

*Effect of drying, radiation and packing on shelf life, physical and organoleptic quality of IM carrot stored at ambient temperature*

***Shelf life***

The shelf life of the IM Carrot increased from 3 to 6 months at ambient temperature, when dried using infrared drier and at radiation dose of 0.5 kGy.

***Moisture***

Moisture content decreased on storage at ambient temperature. The decrease in moisture content was more in tray drier (15.1 per cent) than in infrared drier (9.8 per cent).

***Rehydration ratio***

TDR showed lowest rehydration capacity (43.2%) after 4 months of storage while IRR showed 78% of rehydration capacity even after 6 months of storage at ambient temperature and so IRR was found to be best treatment for IM carrot.

***Organoleptic qualities***

On ZERO day maximum overall acceptability score found in IRR (4.93) and lowest score in TD (4.17). After six months of storage maximum score (3.06) was obtained in IRR and the minimum score (1.47) was recorded in TDR.

***Colour values***

Maximum decrease of L* values, 16.10 units was observed in TDR samples after 4 months of storage IRR showed minimum decrease of L* values (14.89 units) even after 6 months of storage. a* values, which indicate darkening of the sample, improved during storage and at post rehydration stage implying that the redness or reddish orange colour of carrots improved for treated samples. While maximum darkening (a* values 14.49 units) was observed in IRR samples after 6 months.

*Effect of drying, radiation and packing on nutrition and microbial parameters of IM carrot samples stored at ambient temperature*

***Ascorbic acid***

Ascorbic acid content decreased with the increase of storage period. Higher retention 46.25% and 25.28% were observed in IR, IRR samples by the end of four and six months of storage respectively.

***Carotenoids***

Compared to fresh sample, Beta-carotene and total carotenoids content increased on drying, the increase being 3.7- 4.5 and 4.2- 4.7 times more in TD and IR driers respectively. However, carotenoids content decreased on storage in both the treatments. Maximum retention was observed in IRR samples (59.8 per cent of total carotenoids and 52 per cent of β-carotene even after six months of storage).

***Microbial count***

Higher total bacterial count (2.1) and total mould count (2.08) was observed in Tray Dried samples. Throughout the storage period, no coli forms were observed in any sample.

## Discussion

The vegetables may require special pretreatment to reduce the impermeability of their skin to moisture movement. A system, which minimizes exposure to light, oxidation and heat, may help conserve critical bioactive compounds. Determining the appropriate processing conditions is very important for achieving desirable product quality. Optimum pre-treatment for carrot was found to be the control (without any pre-treatment). Control treatment gave the best results when kept for rehydration as it regained its original characters like colour texture, appearance etc., It has also been reported that some fruits and vegetables however, are not very sensitive to oxidation and may not need any pretreatment (Torreggiani *et al*., 2002) Tray drier consumed longer time to attain IM moisture level than infrared drier. Drying at low temperature with infrared lamps has been shown to be a potential useful method for preserving heat sensitive natural products since it is gentle and shortened the processing time significantly (Paakkonen *et al*., 1999).Infra Red drying technology for dehydrating foods has advantages including reduction in drying time, providing uniform temperature in the product while drying, and a better-quality finished products (Dostie *et al*., 1989; Navari *et al*., 1992; Sakai and Hanzawa, 1994; Mongpreneet *et al*., 2002). Generally less drying time and lower temperatures are required for IMF (Levi *et al*., 1985).

A study by Sagar and Kumar (2006) reported that 200 gauge HDPE is most suitable for retention of better quality in respect to colour, flavour, texture and overall quality of the shreds for 4 months at room temperature and 6 months at low temperature (7.0±2$^0$C) followed by 400 gauge LDPE. Most of the studies reported, intermediate moisture fruits and vegetables packed in an oxygen free atmosphere keep an excellent condition for substantial periods, in some cases over two years at ambient temperature.

Radiated IM carrot samples with <30% remained unspoiled and safe over prolonged storage at ambient temperature at different radiation doses. Same moisture range was reported for dehydrated semi moist fruits (Davies *et al*., 1976). The IMF with the moisture content of 28% or less with added preservative are stable and are less prone to microbial spoilage (Levi *et al*., 1985).

Radiation processing in combination of hurdles like reduction in $a_w$ by infrared drying, and gamma radiation dose 0.5 kGy, 400 gauge polyethylene packing successfully reduced the microbial load and showed high product quality at 26.6% moisture level for a period of 6 months at ambient condition (27°C and 65% RH).

The shelf life of the IM Carrot increased from 3 to 6 months at ambient temperature. Radiation treatment appeared to lower the rate of moisture loss on storage with minimal change on rehydration ratio during storage. Intermittent treatment minimized the quality changes where as continuous treatment longer than four hours resulted in discolouration. Infrared dried samples gave the best rehydration ratio and original characters like colour, texture, appearance etc.

The colour, aroma, taste and texture are the important characteristics for acceptability of any product and also good indicators of the adverse physico-chemical changes during storage. Acceptability of IM carrot with IRR was good up to six months at ambient temperature while without radiation, it was four months. Due to reduced drying time, the infra red dried method showed greater nutrient retention, sensory scores and energy saving potential. Hence infrared drying processes along with radiation can be used for colour protection where colour is an important parameter.

Low oxidation rate of ascorbic acid and carotenoids was observed in the study might be due to reduced catalyst concentration at low $a_w$ moisture levels. Losses of the vitamin C content at low-dose of irradiation proved to be not higher than those which occurred in the non-irradiated samples during their shelf-life. The effect of irradiation on vitamin C and carotenoids in fruits has been studied extensively (Thomas, 1986a,b; 1988) and reported that the nutritional value is least affected by irradiation. At low doses, up to 1 kGy the loss of nutrients in fruits and vegetables is insignificant in comparison to other food processing and preservation methods.

Increase of β-carotene and total carotenoids concentration on drying, is not because of processing methods alone, but may be due to more detect ability of these nutrients instrumentally and release of this nutrients from the cellulose (Nagarjuna and Hotchkiss, 1999).

The primary problem in the storage of dehydrated carrot was the loss of colour and the development of unpleasant off-flavor when stored in the presence of oxygen because of the oxidation of carotenoids (Arya *et al*., 1982). IM products packed in high-density PP pouches and exposed to daylight at room temperature (RT) were completely bleached within 15 days, while those in paper-foil pouches (PFP) retained 60% of the original carotenoid content and were acceptable up to two months (Jayaraman *et al*.,1978). Significant carotenoid destruction has been reported to occur during dehydration, and losses have been found to depend on the type of drying method used (Arya *et al*., 1982; Premavalli, 1988; Jayaraman, 1995; Jayaraman *et al*., 1999). The carotenoid oxidation was less in high-moisture products developed from mango and papaya stabilized by hurdle technology (Jayaraman *et al*., 1999). Little information is available on carotenoid stability in carrots at intermediate $a_w$ values IUFOST 2006 in its article reported that carrots naturally provide protection for carotenoids. carotenoids showed maximum stability in the $a_w$ range of 0.341 - 0.537 (Arya *et al*., 1982). Above these $a_w$ values carotenoid stability decreased with a further increase in $a_w$ up to 0.754. Hence Partial dehydration of carrots to intermediate moisture levels could be proposed instead of removing water completely.

IRR recorded least count and low rate of growth throughout the storage period this may be due to a combination of different hurdles of Irradiation, Infrared heating and packing which more effectively inhibited or inactivated microorganisms and food poisoning leaving desired fermentation process unaffected. The individual hurdles were set at low intensities than would be required if only a single hurdle were used as preservative, which may not provide the same effect as the combination of hurdles. The application has proven as very successful, as an appropriate combination of hurdles providing microbial stability, safety and also stable sensory and nutritive properties.

## Conclusion

In the present study, it has been found that a reduction in $a_w$ by Infra red drier and hurdle technology of radiation processing, 400 gauge polythene bags could keep intermediate moisture product safe, acceptable and effective in retention of nutrients up to a period of six months at ambient temperature. The different combinations of hurdles used were more effective than use of a single preservative in large amounts which may not provide the same effect.

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