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Effects of pre-harvest soil management practices and post-harvest processing on phytochemical qualities of turmeric (*Curcuma longa*)

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ABSTRACT

Phytochemicals from turmeric (*Curcuma longa* L.) have a plethora of beneficial, including medicinal uses. To increase their dietary intake, besides minimizing processing losses, exploring pre-harvest soil managements to increase their content naturally may be a suitable option. We made an attempt to assess the effect of pre-harvest soil management by either organic manuring or inorganic fertilization with or without agricultural liming and post-harvest processing through curing followed by drying at 60 ± 2° C on phytochemical properties of turmeric cultivar Meghaturmeric 1 grown in the acid soils of sub-tropical climate of northeast India. Pre-harvest management of soils significantly ($P \leq 0.001$) influenced the phytochemical concentration of turmeric rhizomes. Curcumin concentration in fresh mother rhizome was 15-38% higher than the fresh finger rhizomes. Similarly, fresh mother rhizomes had 21-22% more *β*-carotene and 7-9% more anti-oxidants than the fingers. Post-harvest processing of fresh rhizomes (mother and fingers) to yield dry powder resulted in significant reduction of curcumin (by 2.0-8.0%), *β* carotene (by 8-28%) and anti-oxidant (by 43-64%) concentrations. Pre-harvest soil managements by poultry manuring with liming considerably increased the phytochemical concentrations in the turmeric rhizomes.

Key words: Antioxidant activity, *β*-carotene, Curcumin, Phytochemicals, Soil management, Turmeric

Turmeric (*Curcuma longa* L.) is a rhizomatous spice crop and is native to tropical Southeast Asia (Ravindran *et al.* 2007). Apart from its primary use as a spice and condiment, this plant has many medicinal uses world over (Kamal and Yusuf 2012). Turmeric has several phytochemicals, of which curcuminoids and essential oils are the main active compounds. It is also a rich source of several phenols, minerals and other secondary metabolites, known to have strong medicinal properties (Ravindran *et al.* 2007, Kamal and Yusuf 2012).

Pre-harvest management favours phytochemical synthesis in turmeric, it provides an opportunity to improve food quality. Besides post-harvest processing and extraction methods of phytochemicals, pre-harvest management, specifically cultivation practices also play a significant role in improving quantity as well as quality of phytochemicals in turmeric and other medicinal plants including herbs (Tanko *et al.* 2005). In addition to the preservation of the quality of rhizome by improved post-harvest processing, the natural improvement of phytochemical contents by pre-harvest managements is potentially important. It is still not clear whether extraction from fresh rhizome or post-harvest processed dried powder has any effect on phytochemical concentrations. To improve the quality of phytochemicals in herbs and medicinal plants, one must examine the process of their preparation: from cultivation to extraction as well as specificity of the plant parts since phytochemicals are not evenly distributed in plant parts (Tanko *et al.* 2005). In the present study, we investigated the influence of pre-harvest soil management practices and post-harvest processing on the concentration of phytochemicals in turmeric and whether there is a difference in concentration of phytochemicals between mother (bulb) and finger rhizomes.

MATERIALS AND METHODS

The experiment was conducted during 2010-2013 at the research farm of Soil Science Division, ICAR Research Complex for NEH Region located at mid-altitude Meghalaya (25º 41'N latitude, 91º 55'E longitudes at an elevation of 1080 m msl), northeast India. The study area experiences an average annual rainfall of 2050 mm, with 70% of the total rainfall is received during July to September (Choudhury *et al.* 2013a). The soils were classified as Typic Hapludalf, sandy clay loam in texture, medium in plant available water content (16-18%), strongly acidic in reaction (pH<4.5),

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low in exchangeable bases (<5 meq/100 g soil) but high in organic carbon (>1.46%) contents (Choudhury *et al.* 2013b). Soils are low in available N (160 kg/ha), P (<17 kg/ha), K (<250 kg/ha) and S (<18 kg/ha) contents.

Turmeric (CV Meghaturmeric 1) was grown during 2010-2013 in rainfed dry terraces following flatbed configuration. The experiment was laid out in a randomized complete block design (RCBD) with four replications having seven treatments: natural fertility (without manures and fertilizers), NPK-100% (@180-90-90 kg/ha), farmyard manure (FYM) @5 tonnes/ha, poultry manure (PM) @ 2.5 tonnes/ha, NPK-100% + agricultural lime @ 4 tonnes/ha, FYM @5 tonnes/ha + agricultural lime @ 4 tonnes/ha and poultry manure @ 2.5 tonnes/ha + agricultural lime @ 4 tonnes/ha. Lime was broadcasted 25 days before planting and manures were applied 10 days after lime application. Turmeric rhizomes were harvested at 250 days after planting. Freshly harvested rhizomes were washed with clean water and about 100 g of freshly harvested cleaned mother, primary and secondary (MPS) rhizomes of each were peeled, sliced and dried at 18-20º C temperature and 70-74% mean relative humidity in laboratory shade for estimation of phytochemicals-curcumin, *β*-carotene and antioxidant activities (AA).

Freshly harvested rhizomes were immediately cured up to moisture level of 8% by boiling in plain water for 10 min followed by removal of peels and manual slicing. Sliced rhizomes were dried in cabinet air dryer at 60±2° C for 6-7 hr. Dried samples were grounded in laboratory grinder into a fine powder (less than 60 meshes). This dry powder was used for determination of curcumin, *β*-carotene content and antioxidants for MPS rhizomes separately.

Curcumin content was estimated by ASTA (American Spice Trade Association 1997) procedure. The curcumin content of the samples were determined with the following formula.

$$\text{Curcumin (\%)} = \frac{\text{Absorbance of sample} \times \text{Dilution factor}}{\text{Factor derived from standard} \times \text{Weight of the sample}} \times 100$$

Beta (β) - carotene content of turmeric samples was determined by using the colorimetric method of Srivastava and Kumar (2002). The OD was recorded at 452 nm and β-carotene was expressed as mg/100 g of sample by the following formula

$$\beta - \text{Carotene}\left(\frac{\text{mg}}{100\text{g}}\right) \frac{\text{OD} \times 13.9 \times 104 \times 100}{\text{Weight of the sample} \times 560 \times 1000}$$

where OD is optical density, V is volume of the extract (ml) and W is weight of the sample (g).

Antioxidant activity (AA) of the samples were determined using the ferric reducing antioxidant power (FRAP) assay of Benzic and Strain (1996) as a measure of "Antioxidant Power." The results were expressed as micromoles of trolox equivalents per gram of samples.

Statistical analysis was performed with SAS Version 9.2 (SAS Institute Inc., Cary, NC, USA). SAS's PROC GLM procedure was used to conduct Analysis of Variance to determine the statistical significance of treatment effects. Multiple means comparison was completed by comparing the least squares means of the corresponding treatment combinations with Duncan's Multiple Range Test (DMRT) at 0.05 and 0.001 probability level of significance. Pearson's correlation coefficient was used to determine the strength of relationship among the treatments.

RESULTS AND DISCUSSION

Effect of pre-harvest management and post-harvest processing on curcumin contents of turmeric rhizomes

During both the seasons of 2012 and 2013, curcumin content (average) of fresh mother rhizome was significantly ($P \leq 0.05$) higher over fingers (primary and secondary rhizomes) (Table 1). The curcumin contents decreased from mother to primary and then secondary rhizomes in both fresh rhizome and post-harvest processed dry powder. Post-harvest processing to yield dry powder resulted in reduction of curcumin content of mother and fingers (Table 1). Interaction of year during pre- and post-harvest managements on curcumin content was non-significant ($P < 0.05$). Phytochemical constituents are not evenly distributed in all plant parts (Tanko *et al.* 2005) and present study also affirmed a significant variation of curcumin content in mother and finger rhizomes. Higher curcumin contents in mother rhizomes than fingers were also reported by Rakhunde *et al.* (1998).

Pre-harvest managements significantly ($P \leq 0.001$) influenced curcumin content of fresh mother, primary and secondary (MPS) rhizomes (Fig 1). Application of inorganic fertilizers-NPK resulted in 31-43% increase in curcumin content of mother rhizome as compared to without NPK fertilizers. Addition of lime (@ 4 tonnes/ha) along with fertilizers-NPK resulted in an additional increase of over 6-14% and recorded the maximum amount of curcumin content (5.97-6.17%) in mother rhizome. Similarly, application of organic manures either PM or FYM also increased curcumin content of mother rhizomes by 18-26% in 2012 and 28-36% in 2013 over control. An additional increase of 6-13% in 2012 and 6-17% in 2013 was observed when lime (@ 4 tonnes/ha) was applied with organic manures (PM or FYM) but PM was more effective in increasing the curcumin content than FYM during both the seasons. Compared to mother rhizomes, curcumin content of primary rhizomes was 11-26% less in 2012 and in 2013, it was 8.5-19.0% less across all pre-harvest managements while the corresponding reduction in secondary rhizome was 31-42% in 2012 and 34-40% less in 2013 (Fig 1). On shifting from control to inorganic fertilization and manuring with PM and FYM, primary and secondary rhizomes also exhibited a significant increase in curcumin content (Fig 1). Our reported values of curcumin content in the sub-tropical climate was comparable to the

Table 1 Effect of post-harvest processing on (a) curcumin, (b) *β* carotene and (c) antioxidant properties of mother, primary and secondary rhizomes of turmeric (Mean of pre-harvest treatments ± SD)

Rhizome*	Curcumin (%)			
	Fresh-2012	Fresh-2013	Dry powder-2012	Dry powder-2013
Mother	5.27 ± 0.11	5.24 ± 0.17	4.86 ± 0.16	4.77 ± 0.21
Primary	4.41± 0.20	4.45 ± 0.18	4.17 ± 0.15	4.18 ± 0.18
Secondary	3.22 ± 0.12	3.25 ± 0.14	2.95 ± 0.11	2.91 ± 0.10
Average	4.30^{a} ± 0.32	4.32^{a} ± 0.39	4.00^{b} ± 0.34	3.95^{b} ± 0.37
	β-carotene (mg/100 g)			
Mother	77.15 ± 2.89	76.86 ± 1.59	57.85 ± 1.86	57.71 ± 1.71
Primary	76.48 ± 1.56	75.1 ± 1.18	56.41 ± 1.63	55.1 ± 1.66
Secondary	60.49 ± 1.35	59.1 ± 1.67	51.13 ± 1.67	50.89 ± 1.19
Average	71.37^{a} ± 8.2	70.32^{a} ± 8.55	55.09^{b} ± 3.25	54.56^{b} ± 3.08
	Antioxidant (μ mol trolox/g)			
Mother	15.33 ± 0.39	15.56 ± 1.21	8.72 ± 0.86	8.81 ± 0.61
Primary	14.24 ± 0.76	14.31 ± 0.78	7.20 ± 0.64	7.32±0.56
Secondary	13.91 ± 0.88	14.37 ± 0.71	5.05 ± 1.07	4.99 ± 0.39
Average	14.49^{a} ± 0.72	14.75^{a} ± 0.93	6.99^{b} ± 1.19	7.04^{b} ± 1.66

LSD at P = 0.05: Year = non-significant (ns); rhizome = 0.872; processing (fresh/dry) = 1.07; year × rhizome = ns; year × processing = ns; *average of all treatment combinations

reported values of turmeric from the most parts of Northeast India (3.0-5.5%) (Ravindran *et al.* 2007).

Some workers also reported that pre-harvest managements, particularly addition of inorganic fertilizers-N, P, K, S and Mg significantly increased curcumin contents of turmeric (Bose *et al.* 2008, Kamal and Yusuf 2012) and this might be due to robust the vigorous vegetative growth which possibly resulted in the increased synthesis of curcumin content in the rhizomes. Akamine *et al.* (2007) also reported that inorganic elements, particularly K followed by P are actively involved in curcumin formation of turmeric. On addition of organic manures (poultry manure/neem/mustard cake), Kamal and Yousuf (2012) also recorded 8-15% increase in curcumin content of turmeric cultivar-BARI Halud-3 in Gazipur, Bangladesh. Liming of acid soils (pH<4.6) resulted in an additional increase of 5-11% curcumin content in the mother rhizomes, mostly due to increase in availability of Ca+Mg elements by >20% and 0.2 unit increase in pH (4.79) in the growing media, which might have favoured higher curcumin synthesis in turmeric rhizomes (Bose *et al.* 2008).

On post-harvest processing to yield dry powder, curcumin content of mother rhizome from pre-harvest managements (organic manuring alone or in combination with lime) decreased by 9-11% in 2012 and in 2013, the corresponding reduction was 9-14% (Fig 1). In contrast, pre-harvest managements of control as well as inorganic fertilized treatment didn't experience any significant reduction in curcumin content and remained stable on post-harvest processing. In post-harvest processed dry powder from fingers as well, residual effect of inorganic fertilization with lime helped in maintaining the stability of curcumin extractability. But on application of organic manures alone during pre-harvest management, curcumin content registered reduction in fingers (Fig 1). High temperature (> 60° C) during post-harvest processing to dry powder caused easy degradation of volatile chemicals as well as decomposition of curcumin extractability. Curcumin are readily decomposed when exposed to bright light and sensitive to high temperature or oxidative conditions (Buescher and Yang 2000).

Effect of pre-harvest management and post-harvest processing on β-carotene contents of turmeric rhizomes

Concentration of *β*-carotene content of fresh rhizomes

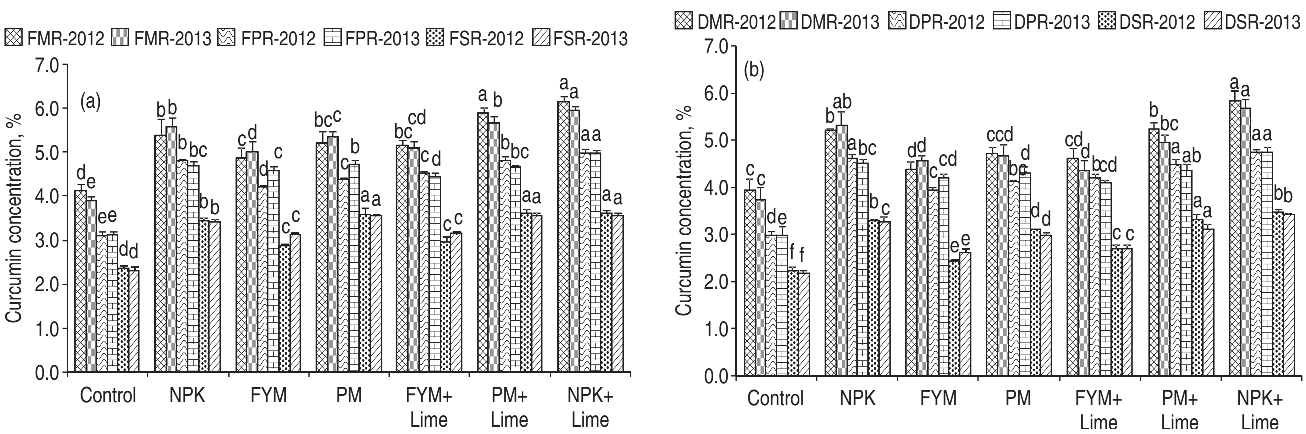

Fig 1 Effect of pre-harvest management (a) and post-harvest processing (b) on curcumin content of turmeric rhizomes (replications= 4; Mean ± SD). MR: mother rhizome, PR: primary rhizome; SR: secondary rhizome. F: fresh, D: dry. Means in the same graph followed by common letters (a-e) are statistically non-significant at *P*<0.001 for treatment differences while interaction of year × treatment was non-significant at *P*<0.05.

was comparable between mother and primary rhizomes. However, in secondary rhizome, it was significantly ($P \leq 0.001$) less (21-23% in 2012 and 11-12% in 2013) than the mother rhizome (Table 1). Post-harvest processing during both the seasons (2012 and 2013) reduced β–carotene content at higher rate (>25%) in mother and primary rhizomes than the secondary rhizomes (<16% reduction). As a result, β- carotene content in dry powder from mother and fingers were statistically ($P \leq 0.001$) comparable (Table 1).

Different pre-harvest managements significantly ($P \leq 0.001$) affected the concentration of β-carotene content in the fresh mother rhizome and fingers (Fig 2). Among the pre-harvest managements, application of PM with lime showed the highest amount of β-carotene in mother and finger rhizomes. Application of PM alone increased β-carotene content by 9-11% in mother and 6-13% in primary rhizomes over control. Addition of lime with PM resulted in another 5-8% increase of β-carotene content of mother rhizome while 3-8% increase was also recorded in primary rhizomes. FYM application alone or in combination with lime also increased the β-carotene content in mother and finger rhizomes over the control. Similarly, when NPK was applied with lime, a significant ($P \leq 0.001$) increase in β-carotene content in fresh mother and fingers was recorded over NPK alone. Application of PM alone increased the β-carotene content by 17-24% ($P \leq 0.001$) over control and with lime; an additional 2-6% increase was recorded in secondary rhizome. In the present study, we observed significantly ($P \leq 0.001$) higher β-carotene content in organically grown turmeric. Similar observations of higher carotene content of tomatoes and carrots grown with organic manures were also reported by other workers (Ragab and Khalid 2010). The higher β-carotene content in organic manuring during pre-harvest management might be due to the suppression effect of organic manures on protein content (Ragab and Khalid 2010).

Due to the inadequacy of information on β-carotene content of turmeric, our reported values of 70 mg/100g in fresh rhizome could not be compared with other studies. However, compared to β-carotene content of fresh carrot, tomato (Ragab and Khalid 2010), and broccoli florets (Nath *et al*. 2011), our reported values for fresh turmeric were many folds higher.

Post-harvest processing of fresh rhizomes to yield dry powder resulted in significant ($P \leq 0.001$) decline of β-carotene content in mother and fingers across all pre-harvest treatments. Dry powder from fingers grown under pre-harvest management practices of poultry manure with lime recorded significantly ($P \leq 0.001$) higher β-carotene content. Carotenoids are relatively heat stable during drying processes, but high temperatures (>50° C) may affect these compounds by decreasing their level at the end of the process (Goula and Adamopoulos 2010). On post-harvest curing followed by oven drying at 60±2° C in a cabinet laboratory drier, we also observed the reduction in β-carotene content of turmeric by 22%. Similarly, Cui *et al.* (2004) also reported a carotenoids loss of about 30% during drying of carrots at 60-65° C in a cabinet laboratory drier.

Effect of pre-harvest management and post-harvest processing on antioxidant contents of turmeric rhizomes

Mean antioxidant activities (AA) were significantly ($P \leq 0.001$) higher in fresh mother rhizome than the fingers (Table 1). Post-harvest processing of fresh rhizomes to yield dry powder resulted in significant ($P \leq 0.001$) reduction of antioxidants by 43-49% in mother and primary rhizomes while the corresponding reduction in secondary rhizome exceeded 63%. Concentration of AA in processed dry powder was also significantly ($P<0.01$) higher in mother rhizome over fingers (Table 1).

Concentration of AA across pre-harvest managements varied significantly across mother and finger rhizomes (Fig 3). Among the different treatments, poultry manures (PM) with or without lime application yielded the maximum AA in mother rhizome and fingers. The significant increase in AA on poultry manuring might be due to the synergistic effect of higher antioxidant components like β-carotene content and to some extent, curcumin contents. This was also affirmed from a very strong positive correlation between AA and β-carotene (r= +0.86-0.88) as well as curcumin (r= +0.59-0.63) contents. Synergistic effects were also found among phenolic constituents, antioxidant

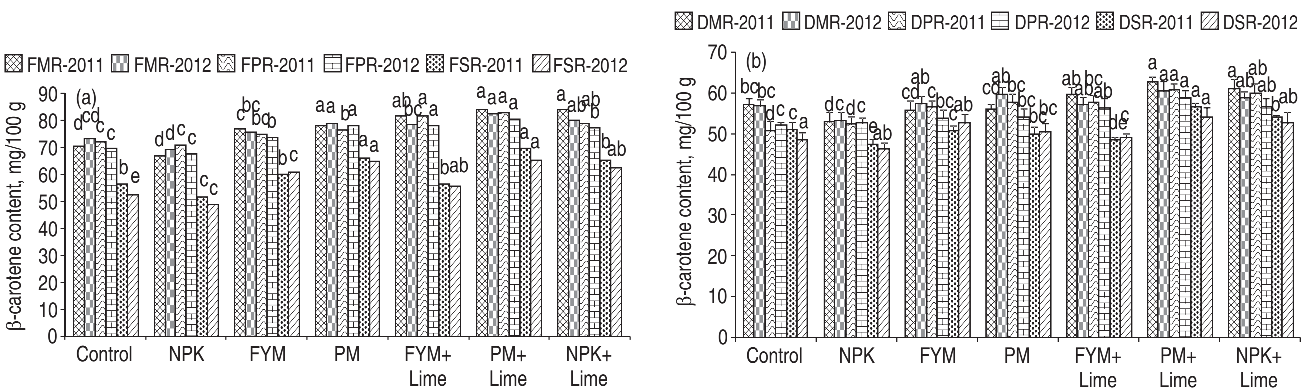

Fig 2 Effect of pre-harvest management (a) and post-harvest processing (b) on β-carotene content of turmeric rhizomes (replications= 4; Mean ± SD). MR: mother rhizome, PR: primary rhizome; SR: secondary rhizome. F: fresh, D: dry. Means in the same graph followed by common letters (a-e) are statistically non-significant at $P<0.001$ for treatment differences while interaction of year x treatment was non-significant at $P<0.05$.

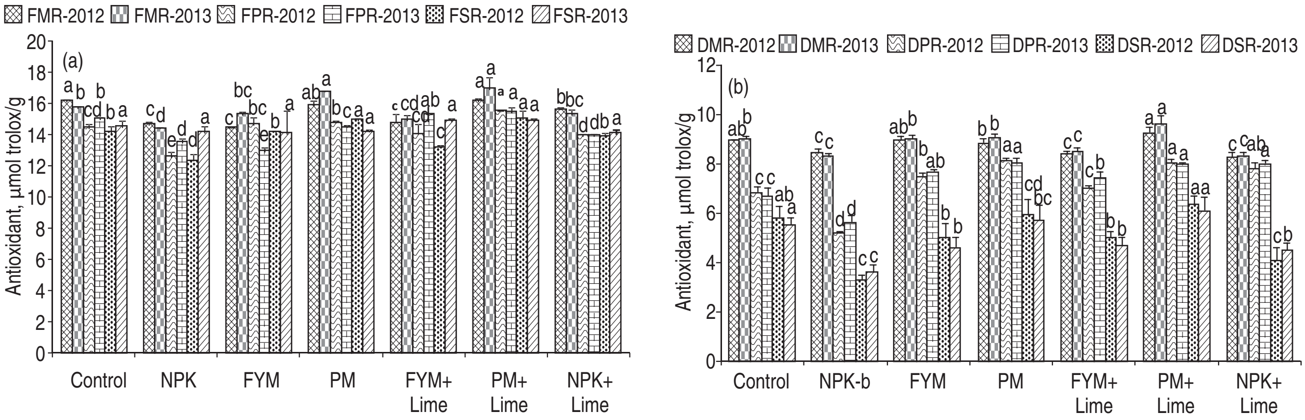

Fig 3 Effect of pre-harvest management (a) and post-harvest processing (b) on antioxidant activities of turmeric rhizomes (replications= 4; Mean ± SD). MR: mother rhizome, PR: primary rhizome; SR: secondary rhizome. F: fresh, D: dry. Means in the same graph followed by common letters (a-e) are statistically non-significant at P <0.001 for treatment differences while interaction of year x treatment was non-significant at P <0.05.

activity and other chemical constituents which may contribute to the potential of antioxidants (Ragab and Khalid 2010). However, pre-harvest management practices of inorganic fertilization-NPK significantly ($P \leq 0.001$) reduced AA concentration by 9.4-10% in fresh mother and 10.0-14.3% in primary rhizomes.

Post-harvest processing of fresh rhizomes to dry powder significantly ($P \leq 0.001$) reduced the AA across all pre-harvest management practices: 38-45% reduction in mother, 44-58% in primary and 58.9-74.5% in secondary rhizome powder respectively (Fig 3). The maximum AA of dried powder of mother and fingers was recorded in pre-harvest poultry manuring with lime. Similar observations of significant reduction in AA of turmeric on drying fresh rhizomes to dry powder were reported by Cousins *et al.* (2007). Antioxidant compounds might also be vaporized or degraded thermally through the heating process during post-harvest processing of fresh rhizomes (Cousin *et al.* 2007).

Interaction analysis also reflected a significant (P<0.05) effect of pre-harvest treatments, post-harvest processing and rhizome parts (mother/fingers) on curcumin, β-carotene content and antioxidants while the interaction of year (2012 and 2013) with pre-and post-harvest managements remained non-significant (Table 1, Fig 1-3).

Pre-harvest managements of turmeric with poultry manure with lime significantly influenced the phytochemical properties, particularly curcumin and β-carotene contents. Thus, pre-harvest managements can be a potential option to increase phytochemicals naturally in turmeric rhizomes. Concentration of phytochemicals reflected that mother rhizome is the richest source followed by primary and secondary rhizomes, respectively. Besides curcumin, fresh rhizome of turmeric can be a natural source of β-carotene content and antioxidants, comparable or even better than some of the most widely used sources like vegetables (carrot, tomatoes, chilies etc.) and spices. Adopting commonly used post-harvest processing of fresh rhizomes considerably reduced β-carotene content and antioxidants to the extent of 22-52%. Future scope, thus, lies in giving emphasis to pre-harvest soil managements for increasing phytochemicals naturally while exploring suitable post-harvest processing to minimize the losses of phytochemicals in turmeric.

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