



Source sink relationship, dry matter and starch partitioning in developing ginger rhizomes during different growth stages

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Abstract

Source sink relationship, dry matter and starch partitioning, rhizome bulking process in relation to dry matter and starch partitioning in developing rhizomes and growth and gas exchange parameters were studied in three popular varieties of ginger viz., IISR Varada, IISR Mahima and IISR Rejatha. Results revealed that maximum tiller production and leaf area accumulation occurred between 60 and 120 days after planting (DAP) in all three varieties. Photosynthetic rate and hormone contents (auxin and cytokinin) increased from 90-120 DAP, peaked at 120 DAP and then started declining. Biomass partitioning data revealed that the active biomass accumulation stage was between 60 and 150 DAP in ginger. The dry matter accumulation pattern in rhizomes also revealed that maximum dry matter accumulation in rhizomes also occurred between 60 and 150 DAP in all the three varieties. Maximum starch accumulation in the rhizomes also occurred during the same period. These results suggest that most of the rhizome bulking process occurred between 60 and 150 DAP in ginger. Total biomass accumulation, dry matter accumulation and starch accumulation in rhizomes followed similar trends.

Keywords: Bulking, ginger source, partitioning, photosynthetic rate, rhizome, sink, transpiration rate

Introduction

Source sink relationship and partitioning of dry matter and metabolites in ginger form the basis for understanding the rhizome development process. Initiation, bulking and termination of rhizome development in ginger are not studied. Proper understanding of these development stages may help in regulating the rhizome growth externally based on our needs. Plant hormones may have a critical role in rhizome initiation and bulking. Similarly, the role of photosynthesis in rhizome development is not clear. The seed rhizome size influences the final rhizome bulking and yield, and the study showed that the greater the seed rhizome size, the greater the fresh rhizome production (Suhaimi *et al.*, 2016). There are a few studies in potato in this direction. Root mass was negatively correlated with early tuber bulking in potato. However, root mass generally shows positive correlations with shoot mass and final tuber yield (Iwama, 2008). The

source-sink relationship was modified by a sink extension in potato; the foliar application of K_2SO_4 accelerated the tuber development. Potato plants expressing chimeric cytokinin synthesis gene had better shoot development and tuberization (Tao *et al.*, 2010), indicating the influence of cytokinins on tuber development. In sweet potato, the growth rate decreased between 45 and 75 days after planting, which may be related to tuberization and secondary vine onset. Later, a significant increase in growth rate was noticed till 90 days after planting, which may be associated with the efficient accumulation of biomass in tubers (Pérez-Pazos *et al.*, 2021). But information is lacking on source-sink transition, partitioning of dry matter and metabolites to various organs during different growth stages, rhizome bulking process and the relationship between photosynthesis and rhizome development *etc.* Hence, the present study was conducted with the following objectives.

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(i) To study the growth and biomass accumulation pattern in leaf, stem, root and rhizomes during different growth stages in three ginger varieties, (ii) to study the influence of gas exchange parameters and endogenous hormonal (auxin and cytokinin) levels on the development of rhizomes and (iii) to study the rhizome bulking process both in terms of dry matter and starch accumulation in rhizomes.

Materials and methods

Ginger varieties *viz.*, IISR Varada, IISR Rejatha and IISR Mahima were planted in ICAR-IISR Experimental Farm, Peruvannamuzhi in RBD with five replicates containing 40 plants in each replication. Six plants from each of these varieties were sampled (destructive sampling) at 30-day intervals starting from 60 days after planting (DAP) for dry matter and metabolite partitioning and hormonal studies. Observation on plant height, number of leaves, leaf area and number of tillers per plant were also recorded at an interval of 30 days starting from 60 DAP. Leaf area was determined as per Kandiannan *et al.* (2009). Indole-3-acetic acid (IAA) and cytokinin were estimated using the ELISA kits (Sigma Aldrich) for IAA and zeatin riboside detection. One gram of leaf sample was cut into small pieces, ground in 5 mL of 50 per cent methanol under ice-cold condition, centrifuged at 10000 rpm for 15 minutes; the supernatant was collected and was directly used for IAA and zeatin riboside quantification. Starch was estimated using the anthrone method and reducing sugars by the Nelson-Somogyi method (Sadasivam and Manickam, 2005). Photosynthetic rate, transpiration rate and leaf temperature were measured *in situ* at 3, 4 and 5 months after planting using CI-340 photosynthesis system (CID Inc, USA).

Statistical analysis was conducted using the mstatc package.

Results and discussion

Morphological parameters in ginger varieties

Morphological parameters such as plant height, number of tillers per plant, number of leaves and leaf area per plant were recorded in ginger varieties *viz.*, IISR Varada, IISR Rejatha and IISR Mahima at 60, 90, 120 and 150 days after planting. IISR Varada recorded the maximum number of tillers at all growth stages, IISR Mahima recorded maximum leaf area per plant, while IISR Rejatha recorded maximum plant height. IISR Rejatha recorded the least leaf area per plant (Table 1). Maximum tiller production and leaf area accumulation occurred between 60 and 120 days in all three varieties.

Biomass partitioning to various organs during growth stages

Partitioning studies in three different varieties of ginger (*viz.*, IISR Varada, IISR Rejatha and IISR Mahima) showed that at 60 days after planting (DAP), shoots received 70.4 to 71.8 per cent biomass and rhizomes received 21.0 to 22.6 per cent while at 150 DAP, shoots received 22.4 to 29.0 per cent and rhizomes received 67.0 to 73.4 per cent of the total biomass (Table 2). Among the varieties, IISR Varada showed maximum partitioning of dry matter into rhizomes and minimum into the root and shoot compared to other varieties at all the observation days. Biomass partitioning data revealed that active biomass accumulation stage is between 60 and 150 DAP in all three varieties. Till 60 DAP, the shoot was the major sink which received about 70 to 72 per cent dry matter in different varieties. But at 90 DAP, dry matter partitioning to shoot and rhizome were almost equal;

Table 1. Morphological parameters in ginger varieties at different growth stages

Variety	Plant height (cm)				No. of tillers per plant				No. of leaves per plant				Leaf area per plant (cm ²)			
	60 DAP	90 DAP	120 DAP	150 DAP	60 DAP	90 DAP	120 DAP	150 DAP	60 DAP	90 DAP	120 DAP	150 DAP	60 DAP	90 DAP	120 DAP	150 DAP
IISR Rejatha	24.7	32.5	38.3	45.5	1.6	4.5	6.1	7.7	14.3	78.3	94.2	107	273.5	1497.9	1802.0	2046.9
IISR Mahima	23.2	31.7	36.8	43.8	1.4	5.0	6.5	8.1	14.5	76.2	91.0	102	328.9	1728.2	2063.9	2313.6
IISR Varada	22.4	30.5	35.7	42.2	1.5	5.2	7.0	8.9	15.0	80.1	96.5	112	310.3	1653.9	1992.5	2311.5
CD (at 5%)	NS	NS	2.4	2.6	NS	NS	0.5	0.6	NS	3.2	3.6	4.5	23.4	41.2	35.2	26.3

Table 2. Dry matter partitioning in ginger varieties

Days after planting	Total DW per plant (g)	Shoot (%)	Rhizome (%)	Root (%)
IISR Mahima				
60	4.3 (6.9) *	71.2	21.4 (21.4) **	7.4
90	23.6 (37.9)	48.2	46.1 (24.7)	4.7
120	41.8 (67.1)	37.2	59.0 (12.9)	4.0
150	56.1 (90.0)	29.0	67.0 (8.0)	4.0
180	62.3 (100)	22.0	74.2 (7.2)	3.8
IISR Rejatha				
60	4.9 (8.1)	71.8	21.0 (21.0)	7.2
90	22.5 (37.2)	47.3	48.3 (27.3)	4.3
120	39.4 (73.5)	36.1	60.2 (11.9)	3.7
150	53.2 (90.5)	27.3	68.9 (8.7)	3.8
180	58.4 (100)	20.9	75.4 (6.5)	3.7
IISR Varada				
60	5.8 (8.3)	70.4	22.6 (22.6)	7.0
90	28.7 (42.7)	44.2	50.8 (28.2)	5.0
120	47.8 (74.5)	31.3	64.3 (13.5)	4.4
150	63.3 (93.9)	22.4	73.4 (9.1)	3.3
180	67.8 (100)	18.1	78.9 (5.5)	3.0

*values in parentheses show % dry matter, ** values in parentheses show the incremental % dry matter accumulation between previous and present DAP

in fact, rhizomes received more than shoot in IISR Varada. Hence, it can be said that the transition stage of shoot from the sink to the source is at 90 DAP. Radioactive labeling studies by Zhao *et al.* (1987) showed assimilates were translocated mainly to shoots and leaves during the seedling stage. Rhizomes received more label

proportionally as the plants aged compared to above-ground parts. The main shoots contributed most to rhizome formation. Secondary shoots were not so efficient, and the youngest shoots contributed little to assimilation or export of ^{14}C (Zhao *et al.*, 1987; Xu *et al.*, 2004). Up to the vigorous growth stage of rhizomes, carbon

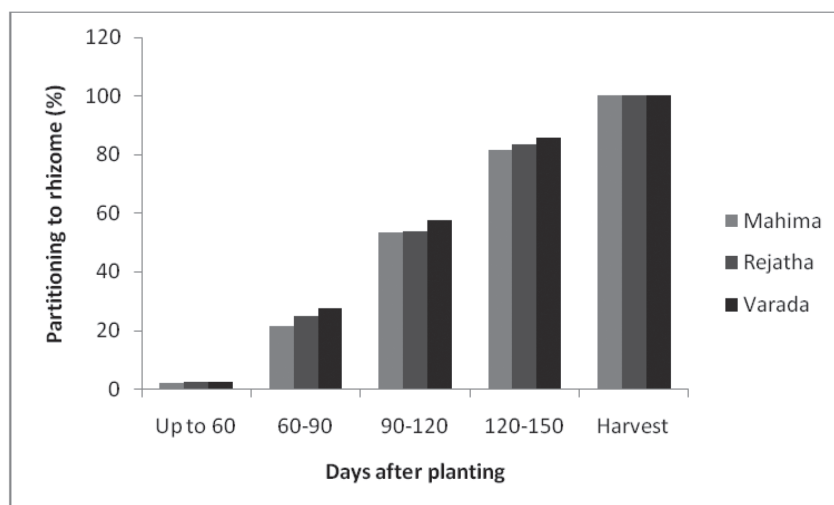


Fig. 1. Partitioning of dry matter to rhizomes at different crop growth stages

Table 3. Plant hormones in ginger

Variety	IAA (p moles)				Zeatin riboside (p moles)			
	60 DAP	90 DAP	120 DAP	150 DAP	60 DAP	90 DAP	120 DAP	150 DAP
IISR Rejatha	22.6	45.4	40.1	20.4	14.4	33.7	26.1	15.3
IISR Mahima	19.4	46.5	38.1	21.7	12.2	28.5	24.7	13.4
IISR Varada	21.5	52.0	43.8	22.4	14.8	35.2	30.3	14.2
CD at 5%	NS	3.1	2.8	1.6	NS	2.1	3.4	NS

assimilates mainly transported from the leaves to the rhizomes. Thus the rhizomes became the growth centres. In the present study also, after 150 DAP, the assimilate transport to the rhizome reduced, which could be because the active growth stage of the rhizome is over and that most of the assimilates from the shoot would have already been translocated to the rhizome, thus leading to reduced translocation rate.

The dry matter accumulation pattern in rhizomes revealed that maximum dry matter accumulation in rhizomes occurs between 60 and 150 DAP in all three varieties. The dry matter accumulation up to 60 DAP, and after 150 DAP was very less (Fig. 1). As the entire shoot is dried up at harvest, partitioning to rhizomes is represented as 100 per cent (which is not true in the real sense). We can infer that the rapid rhizome development phase is between 60 and 150 days (the complete maturity of the crop occurred between 195 and 200 DAP).

Starch and hormone accumulation

Maximum starch accumulation in rhizomes occurred during 60-150 DAP in all three varieties. Starch accumulation increased from 6.4 to 40.4 per cent during this period in different varieties. In contrast, the starch content in the leaves was maintained at 6-7 per cent during the entire growth period (Fig. 2). IAA and zeatin riboside contents in rhizomes increased from 60 to 90 DAP, almost maintained up to 120 DAP and then declined. IISR Varada accumulated the highest starch, auxin and cytokinin at all growth stages. The decrease in IAA and zeatin riboside contents after 120 DAP maybe because these were utilized for rhizome growth, hence maximum dry matter accumulation in rhizome during this period. Earlier studies have shown that rhizome yield can be manipulated through growth regulators during the active growing period. Obasi and Atanu (2004) reported that rhizome yield significantly improved (36.4% increase) by applying 250 ppm CCC during the

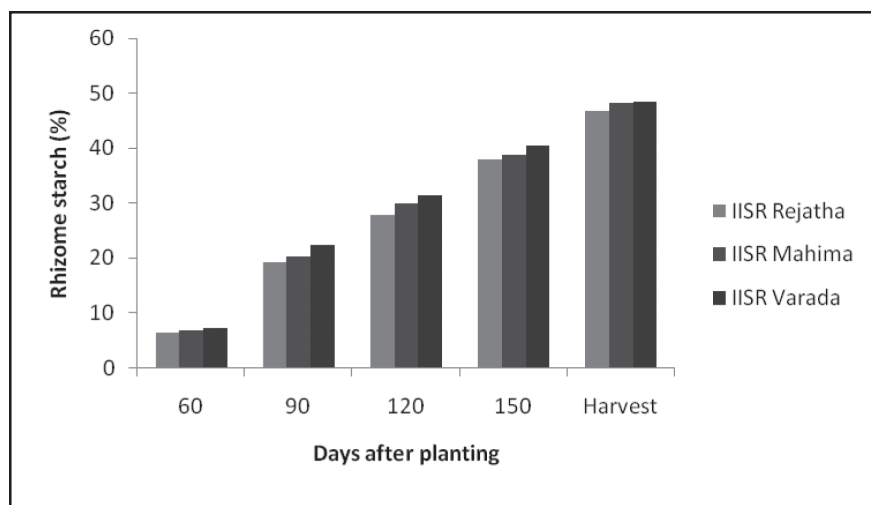
**Fig. 2. Starch accumulation in rhizomes at different growth stages**

Table 4. Gas exchange parameters in ginger varieties

Variety	Photosynthetic rate (μ moles $m^{-2} s^{-1}$)			Transpiration rate (m moles)			Stomatal conductance (μ moles)		
	DAP			DAP			DAP		
	90	120	150	90	120	150	90	120	150
IISR Rejatha	6.3	7.0	5.8	2.71	3.12	2.51	0.08	0.10	0.07
IISR Mahima	6.5	7.4	6.0	2.78	3.18	2.56	0.08	0.11	0.07
IISR Varada	7.1	8.2	7.0	2.97	3.34	2.89	0.09	0.11	0.09
CD (5%)	0.4	0.6	0.5	NS	NS	0.21	NS	NS	NS

active rhizome growth period. Starch and crude fibre contents showed a significant positive correlation with yield, while the crude fibre was negatively correlated (Shankar and Muthuswami, 1985). Phogat and Singh (1987) reported that 200 ppm ethrel enhanced rhizome yield.

The starch accumulation pattern in rhizomes is depicted in Figure 2. The starch accumulation increased with an increase in rhizome growth and reached maximum at harvest. Xu *et al.* (2008) also noted that starch and soluble sugar contents of fresh rhizomes increased with growth. Like dry matter accumulation, maximum starch accumulation occurred between 60 and 150 DAP. Per cent starch accumulation before 60 and after 150 DAP was very less. From both dry matter and starch accumulation pattern, it can be concluded that most rhizome bulking in ginger occurs between 60 and 150 DAP.

Gas exchange parameters

Photosynthetic rate (P_n) varied from 5.8 to 8.2 in different ginger varieties from 90 to 150 DAP. P_n was maximum (7.0 - 8.2 μ mol $m^{-2} s^{-1}$) at 120 DAP. IISR Varada had the highest P_n (Table 4). For the same P_n , IISR Varada had lower transpiration and stomatal conductance compared to IISR Rejatha and IISR Mahima. Both transpiration rate and stomatal conductance were higher at 120 DAP than 90 DAP in all three varieties. Varada had a lower transpiration rate compared to other varieties. P_n increased from 90 to 120 DAP, and after that, it started declining. But the rate of decrease was very less. Thus, we can assume that the photosynthetic rate is maintained from 90 to 150 DAP, positively correlated with the dry matter and starch accumulation in rhizomes during that period.

This again highlights that the metabolic machinery is very active from 90 to 150 days after planting, leading to the rapid development of rhizomes. Earlier studies showed that light plays a major role in photosynthesis. Photosynthesis was saturated at a light intensity of 642 - 867 μ mol $m^{-2} s^{-1}$, which depended on leaf temperature. The light compensation point was in the range of 25 - 69 μ mol $m^{-2} s^{-1}$, and it increased with increasing leaf temperature (Xi Zhen *et al.*, 1998). LAI and DM yield was highest with 20 per cent shading (8.18 and 25.32 g $plant^{-1}$, respectively) and decreased with higher shade levels (Sreekala and Jayachandran, 2001). Wilting markedly decreased the rate of photosynthesis (Zhao *et al.*, 1991). With increased light intensities from 15.61 to 104.81 klx, rhizome yield decreased from 13,487 to 2666 kg ha^{-1} (Shankar and Muthuswamy, 1988).

Conclusion

Maximum tiller production and leaf area accumulation occurred between 60 and 120 days after planting (DAP) in all three varieties. Photosynthetic rate and hormone contents (auxin and cytokinin) increased from 90 to 120 DAP, peaked at 120 DAP and then started declining. Biomass partitioning data revealed that the active biomass accumulation stage is between 60 and 150 DAP. The dry matter accumulation pattern in rhizomes also revealed that maximum dry matter accumulation in rhizomes also occurred between 60 and 150 DAP in all three varieties. Maximum starch accumulation in the rhizomes also occurred during the same period. These results suggest that most of the rhizome bulking process occurs between 60 and 150 DAP in ginger.

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