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Changes in Biomass with the Plant Age of Sugar Palm (*Arenga pinnata* Merr.) Grown in Tana Toraja, South Sulawesi, and Tomohon, North Sulawesi, Indonesia

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Abstract: Changes in the biomass of sugar palm shoot (leaf and trunk) with the estimated plant age (EPA, years) were investigated in Tana Toraja, South Sulawesi and in Tomohon, North Sulawesi, Indonesia. In both villages, the fresh and dry weights of the shoot, the trunk and its parts (bark and pith) tended to increase with the EPA, but the change after the emergence of female inflorescences (FIs) was small. On the other hand, those of the leaf and its parts (leaflet, rachis, and petiole and leaf sheath) increased from the early trunk elongation stage to the emergence stage of FIs and reached the maximum value, then decreased toward the dying stage. The ratios of the leaf and the trunk to the shoot weight decreased and increased, respectively, with the EPA, and the ratios were almost the same in the emergence stage of FIs. The fresh and dry weight ratios of the pith to the shoot (trunk) of sugar palms at the optimum harvest stage were in the range of 40–50 (80–85) % and 30–45 (70–80) % in both villages, respectively. However, due to the large variation in the maximum trunk weight of both villages and between individuals of the same growth stage in SB Village, it is necessary to clarify the genetic difference of sugar palms in both villages and the effects of the growing environments and the degrees of male and female inflorescence development and sap collection on the biomass production and starch yield.

Keywords: dry matter percentage, dry weight, fresh weight, leaf, shoot, trunk

Introduction

The sugar palm is widely distributed in the tropical South and Southeast Asia and is an important and versatile palm for persons living in this area (Mogea et al., 1991; Smits, 1996). In particular, Indonesia has been actively collecting sap containing large amounts of sugar, and the sap is used for producing brown sugar (jaggary) and fermented (toddy) and distilled liquor (*Arak*). There are very few reports of the actual conditions of collecting sap of sugar palms, although the authors reported the actual conditions on Muna Island, Southeast Sulawesi Province, Indonesia (Yamamoto et al., 2021a). In addition, sugar palms accumulate large amounts of starch in the pith of their trunks and are known as starch-accumulating palms, but there are few reports on it (Mogea et al., 1991; Smits, 1996). From this background, the authors reported on the starch productivities of sugar palms on Muna Island, described above, and those in Tana Toraja, South Sulawesi, and in Tomohon, North Sulawesi (Yamamoto et al., 2021b, 2021c). The starch productivity of sugar palms is presumed to be closely related to the dry matter production and the distribution of the produced dry matter to each organ or part. In sago palms, differences in the starch productivity of folk varieties are related to the dry matter production, which was mainly determined by the differences in the size of the leaf area and the growth duration until flowering; however, differences in the dry matter distribution ratios to each organ or part were small (Yamamoto, 2015; Yamamoto et al., 2010; 2014; 2016a).

The purpose of this study was to determine changes in the biomass of each organ (leaf and trunk) and its parts (leaf: leaflet, rachis and petiole and leaf sheath; trunk: bark and pith) of the shoot and their weight ratios with the plant age in sugar palms. For this purpose, we measured the fresh and dry weights of each organ and its parts of shoots on the same plants surveyed in the previous report (Yamamoto et al., 2021c) in Tana Toraja, South Sulawesi and in Tomohon, North Sulawesi, Indonesia.

Materials and Methods

1. Survey sites and times

The survey was conducted in Sandabilik (SB) Village, Tana Toraja, South Sulawesi, in September 2013 and in Taratara (Ta) Village, Tomohon, North Sulawesi, Indonesia in September 2014 (Yamamoto et al., 2021c).

2. Sampling survey

The plants sampled in this report are the same as those sampled in the previous report (Yamamoto et al., 2021c). That is, 1 – 3 plants in each of the four growth stages in SB Village (estimated plant age: 5–25 years; 8 plants in total) and 1–2 plants in each of the five growth stages in Ta Village (estimated plant age: 3–16 years; 8 plants in total) from the early trunk elongation (ETE) stage to the dying stage (plants whose sap collection was ended or plants with ages similar to those whose sap collection was ended were described in this way) (Table 1). Regarding the

Table 1. Sugar palm plants harvested for measurements in Sandabilik and Taratara Villages

Plant No.	Estimated plant age (yrs)[1)]	Growth stage (Remarks)
(Sandabilik Village, Tana Toraja, South Sulawesi, Indonesia, 2013)		
1	5	Early trunk elongation
2	5	Early trunk elongation
3	9	Before emergence of female inflorescence (two years before)
4	10	Before emergence of female inflorescence (one year before)
5	16	Emegence of male inflorescence (first male emerged about two years earlier but sap was not collected; 12 female inflorescences emerged)
6	19	Dying (sap collection ended two months earlier; sap collected for 30 months; eight female inflorescences emerged)
7	19	Dying (sap collection ended seven months earlier; sap collected for three years; 14 female inflorescences emerged)
8	25	Dying (sap collection ended one year earlier; 13 female inflorescences emerged)
(Taratara Village, Tomohon, North Sulawesi, Indonesia, 2014)		
11	3	Early trunk elongation
12	4	Early trunk elongation
13	8	Late trunk elongation
14	10	Emergence of female inflorescence (four female inflorescences emerged)
15	11	Emergence of female inflorescence (nine female inflorescences emerged)
16	11	Emergence of male inflorescence (two male inflorescences emerged and sap collection had just started; eight female inflorescences emerged)
17	16	Dying (just before sap collection ended; seven female inflorescences emerged)
18	15	Dying (sap collection ended about one year earlier; seven female inflorescences emerged)

1) Years after seedling stage (estimated by the farmers)

emergence stage of male inflorescences, only one (SB Village) or two male inflorescence(s) (Ta Village) had emerged, so we called the stage "the early emergence stage of male inflorescences (MIs)". The ages (years) of the harvested plants were estimated by the owners of the plants (hereafter, estimated plant age, EPA). These plants were cut down with a chainsaw, and the fresh and dry weights of each part of the shoot were measured as follows. The upper, middle and lower leaves of each plant were separated from the base of the leaf sheath on the trunk, and the fresh weights of the leaflets, rachis, and petiole and leaf sheath were measured; the average values of these were multiplied by the number of leaves to produce each part of the whole leaf. In addition, leaflet (10–140 g), rachis (40–90 g), and petiole and leaf sheath (50–100 g) samples were collected from the centers of the longest leaflets on the left and right sides of the rachis, the rachis, and the petiole and leaf sheath of each sampled leaf, and the fresh weights were measured up to 0.1 g unit with an electronic balance (HL-200 type, Kyoei Co.). The trunk was cut into two part—the upper and lower parts—at the lowest surviving leaf node, and they were cut evenly at 1–4 positions depending on the length. Then, a 2–3 cm thick disk was cut from each cut surface toward the upper part of the trunk (however, toward the lower part of trunk at the uppermost parts of the upper and lower trunks); each disk was then separated into the bark and the outer pith fiber tissue (hereafter, bark) and the inner pith (hereafter, pith), and their weights were measured separately (Yamamoto et al., 2021b, c). Then, 20 to 80 g of the bark and 50 to 90 g of the pith were collected radially (0.1 g unit) by the above-mentioned electronic balance and collected. Furthermore, the trunk was cut from the cutting position of each disk to a length of about 50 cm (log), and the upper and lower diameters and weights were measured with a ruler and a 100 kg bar scale, respectively. Then, the volume of the upper and lower trunks was calculated from their lengths and the average diameters of the logs, and the volume was multiplied by the average density of each log (log weight/log volume) to estimate the upper and lower trunk weights. The sum of the upper and lower trunk weights was taken as the trunk weight per plant.

The collected leaf and trunk samples were dried in a temporary dryer (about 80 °C) for 2 days, brought back to Japan, and further dried at 65 °C for 2 days in a ventilation dryer to measure the dry weight. Then, the dry matter percentage (dry weight/fresh weight × 100) was calculated from the fresh and dry weights of each sample. The average dry matter percentages of each organ and its parts were calculated as the average values of three leaves and of all disks, respectively. The dry weight was calculated by the fresh weight and the average dry matter percentage of each part. The leaf and trunk weights were determined by adding the weights of all parts. In addition, the total weight of the leaf and the trunk was taken as the shoot weight, and the ratio of each organ and part weight to the shoot weight in fresh and dry weights was calculated. Moreover, the fresh and dry weight ratios of each part of leaf and trunk to the leaf and trunk weight, respectively, were also calculated.

In this study, plants with female and male inflorescences were found, but they were not included in the survey for biomass since the inflorescences were not directly related to starch productivity and the variation among plants in terms of the number and degree of development was huge.

Results

1. Fresh weight

Table 2 shows the fresh weights of a shoot and its organs and parts. In both villages, the fresh weights of leaf and its parts did not show significant correlations with the EPA. Those weights increased from the ETE stage to the emergence stage of female inflorescences (FIs) and then changed little during the early emergence stage of MIs and tended to decrease in the dying stage in Ta Village. However, in SB Village, the fresh weights of Plant No. 5 and No. 8 were very heavy, and this tendency was not clear as compared

Table 2. Fresh weights of a shoot and its organs and parts of sugar palms at different growth stages in Sandabilik and Taratara Villages

Plant No.[1)]	Leaf (kg) leaflet	rachis	P+LS[3)]	whole	Trunk (kg) bark	pith	whole	Shoot (kg)
(Sandabilik Village)								
1	84	96	167	347	24	162	186	533
2	91	68	163	322	26	266	293	615
3	210	149	454	813	160	837	997	1809
4	212	138	348	698	210	932	1141	1839
5	477	338	941	1756	636	2151	2787	4543
6	125	75	143	342	321	1417	1738	2080
7	154	166	353	673	432	1415	1847	2520
8	149	205	416	771	667	2434	3101	3871
Average	188	154	373	715	309	1202	1511	2226
SD	126	88	260	467	252	817	1066	1413
CV (%)	67.2	56.8	69.6	65.3	81.3	68.0	70.6	63.5
rs [2)]	*0.172*	*0.422*	*0.268*	*0.275*	*0.884***	*0.905***	*0.902***	*0.772**
(Taratara Village)								
11	64	77	111	251	9	118	127	378
12	135	164	204	504	28	216	244	748
13	438	366	756	1560	253	1470	1723	3283
14	535	405	883	1822	253	1242	1495	3317
15	333	299	485	1118	262	1206	1469	2586
16	434	296	711	1440	286	1570	1856	3296
17	201	146	263	609	351	1264	1615	2224
18	191	126	211	528	413	1037	1450	1978
Average	291	235	453	979	232	1015	1247	2226
SD	168	122	297	583	143	549	670	1149
CV (%)	57.7	51.9	65.5	59.5	61.6	54.0	53.7	51.6
rs [2)]	*0.252*	*0.078*	*0.126*	*0.153*	*0.955****	*0.700*	*0.777**	*0.531*

1) Refer to Table 1. 2) Correlation coefficients with estimated plant age (Table 1). 3) Petiole and leaf sheath. *, **, and ***: significant at $p<0.05$, $p<0.01$, and $p<0.001$, respectively

with that in Ta Village. The maximum leaf fresh weight in SB Village was 1756 kg in the early emergence stage of MIs and 1822 kg in Ta Village in the emergence stage of FIs. The fresh weights of the trunk and its parts tended to increase with the EPA in both villages and had a significant positive correlation with the EPA, with the exception of the pith weight in Ta Village. However, in Ta Village, the pith and the trunk fresh weights changed little after the emergence stage of FIs, changing between 1037–1570 kg and 1450–1856 kg, respectively. In SB Village, the fresh weights of Plant No. 5 and No. 8 were very heavy, and the tendency during this period was not clear compared to that in Ta Village. The shoot fresh weight had a significant positive correlation with the EPA in SB Village, and the maximum value was 4543 kg in the early emergence stage of MIs. The shoot fresh weight in Ta Village was not significantly correlated with the EPA, and it showed the maximum value of 3317 kg in the emergence stage of FIs, and tended to decrease in the dying stage.

Table 3 shows the fresh weight ratios (%) of each organ and part to the shoot weight. In both villages, the fresh weight ratios of the leaf and its parts had significant negative correlations with the EPA, and those of the trunk and its parts had significant positive correlations. The leaf fresh weight ratio decreased from 52–65% in the ETE stage to 16–27% in the dying stage in SB Village and from 67–69% to 27% in Ta Village, then the ratios became almost equal with those of the trunk in the emergence stage of FIs. As for the leaf parts, the fresh weight ratios were higher in the order of petiole and leaf sheath>leaflet ≒ rachis. The trunk fresh weight ratio in SB Village increased from 35–48% in the ETE stage to 73–84% in the dying stage, and in Ta Village from 31–33% to 73%, respectively. The fresh weight ratios of the pith were consistently higher than those of the bark. Moreover, the pith fresh weight ratios in SB Village increased from 30–43% in the ETE stage to 56–68%

Table 3. Fresh weight ratios of each organ and part to the shoot weight of sugar palms at different growth stages in Sandabilik and Taratara Villages

Plant No.[1)]	Leaf (%) leaflet	rachis	P+LS[3)]	whole	Trunk (%) bark	pith	whole	Shoot (%)
(Sandabilik Village)								
1	15.8	18.1	31.3	65.2	4.5	30.3	34.8	100
2	14.8	11.1	26.5	52.4	4.3	43.3	47.6	100
3	11.6	8.3	25.1	44.9	8.8	46.3	55.1	100
4	19.2	12.4	31.4	63.0	6.8	30.2	37.0	100
5	10.5	7.4	20.7	38.7	14.0	47.4	61.3	100
6	6.0	3.6	6.9	16.4	15.4	68.1	83.6	100
7	6.1	6.6	14.0	26.7	17.2	56.1	73.3	100
8	3.8	5.3	10.8	19.9	17.2	62.9	80.1	100
Average	11.0	9.1	20.8	40.9	11.0	48.1	59.1	-
SD	5.4	4.6	9.4	18.8	5.5	13.9	18.8	-
CV (%)	49.3	51.0	45.0	45.9	50.3	28.9	31.8	-
rs [2)]	*-0.884***	*-0.814**	*-0.889***	*-0.899***	*0.964****	*0.832**	*0.899***	-
(Taratara Village)								
11	17.4	21.0	30.6	69.0	2.0	29.0	31.0	100
12	18.1	22.0	27.3	67.4	3.7	28.9	32.6	100
13	13.3	11.1	23.0	47.5	7.7	44.8	52.5	100
14	16.1	12.2	26.6	54.9	7.6	37.4	45.1	100
15	12.9	11.6	18.8	43.2	10.1	46.6	56.8	100
16	13.2	9.0	21.6	43.7	8.7	47.6	56.3	100
17	9.0	6.5	11.8	27.4	15.8	56.8	72.6	100
18	9.7	6.3	10.7	26.7	20.9	52.4	73.3	100
Average	13.7	12.5	21.3	47.5	9.6	43.0	52.5	−
SD	3.3	6.0	7.2	16.0	6.2	10.3	16.0	−
CV (%)	24.4	48.0	33.8	33.6	64.3	24.0	30.4	-
rs [2)]	*-0.930****	*-0.948****	*-0.925****	*-0.967****	*0.922***	*0.946****	*0.967****	-

1) Refer to Table 1. 2) Correlation coefficients with estimated plant age (Table 1). 3) Petiole and leaf sheath. *, **, and ***: significant at $p<0.05$, $p<0.01$, and $p<0.001$, respectively

Table 4. Fresh weight ratios of each leaf part to the leaf weight and each trunk part to the trunk weight of sugar palms at different growth stages in Sandabilik and Taratara Villages

Plant No.[1)]	Leaf (%) leaflet	rachis	P+LS[3)]	whole	Trunk (%) bark	pith	whole
(Sandabilik Village)							
1	24.2	27.8	48.0	100	12.9	87.1	100
2	28.2	21.2	50.5	100	9.0	91.0	100
3	25.8	18.4	55.8	100	16.0	84.0	100
4	30.4	19.7	49.8	100	18.4	81.6	100
5	27.1	19.2	53.6	100	22.8	77.2	100
6	36.4	21.8	41.8	100	18.5	81.5	100
7	22.9	24.6	52.5	100	23.4	76.6	100
8	19.3	26.7	54.0	100	21.5	78.5	100
Average	26.8	22.4	50.8	100.0	17.8	82.2	100.0
SD	5.2	3.5	4.4	0.0	5.0	5.0	0.0
CV (%)	19.3	15.7	8.7	0.0	28.1	6.1	0.0
rs [2)]	*-0.207*	*0.248*	*0.044*	-	*0.814**	*-0.813**	-
(Taratara Village)							
11	25.3	30.4	44.3	100	6.9	93.1	100
12	26.8	32.6	40.5	100	11.4	88.6	100
13	28.1	23.5	48.5	100	14.7	85.3	100
14	29.4	22.2	48.4	100	16.9	83.1	100
15	29.8	26.8	43.4	100	17.9	82.1	100
16	30.1	20.5	49.4	100	15.4	84.6	100
17	33.0	23.9	43.1	100	21.7	78.3	100
18	36.2	23.8	40.1	100	28.5	71.5	100
Average	29.8	25.5	44.7	100.0	16.7	83.3	100.0
SD	3.4	4.2	3.6	0.0	6.5	6.5	0.0
CV (%)	11.5	16.4	8.2	0.0	38.9	7.8	0.0
rs [2)]	*0.928****	*-0.701*	*-0.073*	-	*0.914***	*-0.914***	-

1) Refer to Table 1. 2) Correlation coefficients with estimated plant age (Table 1). 3) Petiole and leaf sheath. *, **, and ***: significant at $p<0.05$, $p<0.01$, and $p<0.001$, respectively

in the dying stage, and in Ta Village from 29% to 52–57%, respectively. Comparing the two villages, the leaf, leaflet, and rachis fresh weight ratios in SB Village were lower and the trunk and pith fresh weight ratios tended to be higher than those in Ta Village.

Table 4 shows the fresh weight ratios (%) of each leaf part to the leaf weight and each trunk part to the trunk weight. As for leaf parts, the leaflet weight ratio in Ta Village showed a significant positive correlation and an increasing tendency with the EPA, but no significant correlations were found in any of the others. The average fresh weight ratios of leaflet, rachis, and petiole and leaf sheath were 26.8, 22.4, and 50.8%, respectively, in SB Village, and 29.8, 25.5, and 44.7%, respectively, in Ta Village. The fresh weight ratio of petiole and leaf sheath in SB Village was considerably higher and the ratios of leaflet and rachis were slightly lower than those in Ta Village. As for the trunk parts, in both villages, the bark and the pith fresh weight ratios significantly increased and decreased with the EPA, respectively. That is, in both villages, the bark and the pith fresh weight ratios changed from about 10% and 90% in the ETE stage to 20–30% and 70–80% in the dying stage, respectively. Differences in the fresh weight ratios of the bark and the pith between both villages were small.

2. Dry weight

Table 5 shows the dry weights of a shoot and its organs and parts. In both villages, the changing patterns of dry weights of the leaf and the trunk and their parts with the EPA were the same as those of fresh weights (Table 2). The dry weights of leaf and its parts were not significantly correlated with the EPA. The maximum leaf dry weight was 757 kg in the early emergence stage of MIs in SB Village and 656 kg in the emergence stage of FIs in the Ta Village. On the other hand, the dry weights of the trunk and its parts showed significant positive correlations with the EPA, such as the fresh weights,

Table 5. Dry weight of a shoot and its organs and parts of sugar palms at different growth stages in Sandabilik and Taratara Villages

Plant No.[1)]	Leaf (kg) leaflet	rachis	P+LS[3)]	whole	Trunk (kg) bark	pith	whole	Shoot (kg)
(Sandabilik Village)								
1	34	39	51	124	7	26	34	158
2	41	25	47	113	9	52	61	174
3	96	60	138	294	79	164	242	537
4	91	57	103	251	122	286	408	659
5	231	148	377	757	405	1017	1423	2179
6	54	30	42	126	162	396	558	684
7	83	82	162	326	274	667	941	1267
8	73	89	160	322	402	978	1380	1702
Average	88	66	135	289	182	448	631	920
SD	62	40	110	209	161	396	557	730
CV (%)	70.8	60.8	81.2	72.4	88.3	88.3	88.3	79.3
rs [2)]	*0.223*	*0.465*	*0.353*	*0.341*	*0.850***	*0.839***	*0.842***	*0.741**
(Taratara Village)								
11	29	29	32	91	2	16	18	108
12	61	62	51	175	9	28	37	212
13	211	137	164	512	111	379	490	1001
14	260	159	237	656	137	353	490	1146
15	152	115	128	395	139	447	586	981
16	218	121	178	516	142	483	625	1141
17	104	71	91	266	176	293	469	735
18	99	56	78	233	249	282	531	764
Average	142	94	120	355	120	285	406	761
SD	82	45	70	196	82	176	239	401
CV (%)	57.8	48.5	58.2	55.1	68.2	61.8	59.0	52.7
rs [2)]	*0.294*	*0.184*	*0.273*	*0.263*	*0.947****	*0.633*	*0.791**	*0.600*

1) Refer to Table 1. 2) Correlation coefficients with estimated plant age (Table 1). 3) Petiole and leaf sheath. *, **, and **: significant at $p<0.05$, $p<0.01$, and $p<0.001$, respectively

except for the pith in Ta Village. However, the change in the trunk dry weight after the emergence stage of FIs in Ta Village was small and maintained at 469–625 kg. In addition, the pith dry weight showed the maximum value of 483 kg in the early emergence stage of MIs, and it tended to decrease in the dying stage. In SB Village, the dry weights of Plant No. 5 and No. 8 were remarkably heavy, and the tendency during this period was not clearly recognized. The shoot dry weight had a significant positive correlation with the EPA in SB Village, and the maximum value was 2179 kg in the early emergence stage of MIs. The shoot dry weights in Ta Village were not significantly correlated with the EPA and showed the maximum value of 1146 kg in the emergence stage of FIs and tended to decrease in the dying stage.

Table 6 shows the dry weight ratios (%) of each organ and part to the shoot weight. Similar to those of the fresh weight, the dry weight ratios of the leaf and its parts decreased significantly with the EPA in both villages, and those of the trunk and its parts increased significantly, except in the pith, in Ta Village. The leaf dry weight ratio decreased from 65–79% in the ETE stage to 19–26% in the dying stage in SB Village and from 83–84% to 31–36% in Ta Village. Then, as with the fresh weight ratios, the dry weight ratios of the leaf and trunk became almost equal in the emergence stage of FIs. As for the leaf parts, the dry weight ratios changed higher in the order of petiole and leaf sheath>leaflet ≥rachis in SB Village and in the order of leaflet>petiole and leaf sheath>rachis in Ta Village. The trunk dry weight ratios in SB Village (Ta Village) increased from 21–35% (16–18%) in the ETE stage to 74–82% (64–70%) in the dying stage. The pith dry weight ratios remained higher than the bark dry weight ratios. In addition, the pith dry weight ratios in SB Village (Ta Village) increased from 17–30% (13–14%) in the ETE stage to 53–58% (37–40%) in the dying stage. As with the fresh weight ratios, the dry weight ratio of the leaf, leaflet, and rachis were lower and those of the trunk and pith were higher in SB Village than those in Ta Village.

Table 6. Dry weight ratios of each organ and part to the shoot weight of sugar palms at different growth stages in Sandabilik and Taratara Villages

Plant No.[1)]	Leaf (%) leaflet	rachis	P+LS[3)]	whole	Trunk (%) bark	pith	whole	Shoot (%)
(Sandabilik Village)								
1	21.6	24.9	32.2	78.7	4.6	16.6	21.3	100
2	23.6	14.4	27.2	65.2	5.2	29.6	34.8	100
3	17.9	11.2	25.8	54.9	14.6	30.5	45.1	100
4	13.8	8.6	15.7	38.1	18.5	43.4	61.9	100
5	10.6	6.8	17.3	34.7	18.6	46.7	65.3	100
6	7.9	4.3	6.2	18.5	23.6	57.9	81.5	100
7	6.5	6.5	12.8	25.7	21.6	52.6	74.2	100
8	4.3	5.2	9.3	18.9	23.6	57.5	81.1	100
Average	13.3	10.2	18.3	41.8	16.3	41.9	58.2	−
SD	7.2	6.8	9.2	22.3	7.6	14.9	22.3	−
CV (%)	54.0	66.2	50.3	53.2	46.8	35.6	38.3	−
rs[2)]	*-0.968****	*-0.789**	*-0.884***	*-0.917***	*0.893***	*0.912***	*0.917***	-
(Taratara Village)								
11	26.8	26.9	30.0	83.7	1.9	14.4	16.3	100
12	28.9	29.4	24.2	82.5	4.1	13.4	17.5	100
13	21.0	13.7	16.4	51.1	11.1	37.8	48.9	100
14	22.7	13.9	20.7	57.3	11.9	30.8	42.7	100
15	15.5	11.7	13.1	40.3	14.1	45.6	59.7	100
16	19.1	10.6	15.6	45.2	12.4	42.3	54.8	100
17	14.2	9.6	12.4	36.2	23.9	39.9	63.8	100
18	13.0	7.3	10.2	30.5	32.5	37.0	69.5	100
Average	20.1	15.4	17.8	53.3	14.0	32.7	46.7	−
SD	5.8	8.2	6.7	20.2	10.0	12.3	20.2	−
CV (%)	28.9	53.3	37.6	37.8	71.5	37.8	43.2	−
rs[2)]	*-0.904***	*-0.820**	*-0.846***	*-0.875***	*0.950****	*0.660*	*0.875***	−

1) Refer to Table 1. 2) Correlation coefficients with estimated plant age (Table 1). 3) Petiole and leaf sheath. *, **, and ***: significant at $p<0.05$, $p<0.01$, and $p<0.001$, respectively

Table 7 shows the dry weight ratios (%) of each leaf part to the leaf weight and each trunk part to the trunk weight. As for the leaf parts, the leaflet weight ratio in Ta Village showed a significant positive correlation with the EPA and the rachis weight ratio showed a significant negative correlation; however, no significant correlations were found in any of the others. The average dry weight ratios of leaflet, rachis, and petiole and leaf sheath were 31.7, 24.1, and 44.2%, respectively, in SB Village and 38.8, 27.7, and 33.5%, respectively, in Ta Village, which indicates that the dry weight ratio of the leaflet was lower and that of the petiole and leaf sheath was higher in SB Village than in Ta Village. As for the trunk parts, in Ta Village, the bark dry weight ratio increased significantly, and the pith dry weight ratio decreased significantly with the EPA. That is, the bark and pith dry weight ratios changed from 11–24% and 77–89% in the ETE stage to 38–47% and 53–63% in the dying stage, respectively. On the other hand, in SB Village, the correlations were not significant but were considerably highly positive in the bark ratio and negative in the pith ratio, and the bark and pith dry weight ratios changed from 15–22% and 78–85% in the ETE stage to 29 and 71% in the dying stage, respectively. Comparing the two villages, in the dying stage, the bark and the pith dry weight ratios were lower and higher, respectively, in SB Village than in Ta Village.

3. Dry matter percentage

Table 8 shows the dry matter percentages of a shoot and its organs and parts. The dry matter percentages of the shoot and all its organs and parts showed significantly or relatively high positive correlations and tended to increase with the EPA in both villages. The leaf dry matter percentage was about twice as high or more than that of the trunk in the ETE stages, but the difference decreased with the EPA, becoming almost equal in the emergence stage

Table 7. Dry weight ratios of each leaf part to the leaf weight and each trunk part to the trunk weight of sugar palms at different growth stages in Sandabilik and Taratara Villages

Plant	Leaf (%)				Trunk (%)		
No.[1)]	leaflet	rachis	P+LS[3)]	whole	bark	pith	whole
(Sandabilik Village)							
1	27.5	31.6	40.9	100	21.7	78.3	100
2	36.2	22.0	41.8	100	15.0	85.0	100
3	32.7	20.3	47.0	100	32.5	67.6	100
4	36.2	22.6	41.2	100	29.9	70.1	100
5	30.6	19.6	49.9	100	28.5	71.5	100
6	42.9	23.5	33.6	100	29.0	71.0	100
7	25.3	25.1	49.6	100	29.1	70.9	100
8	22.7	27.7	49.7	100	29.1	70.9	100
Average	31.7	24.1	44.2	100.0	26.8	73.2	100.0
SD	6.6	4.0	5.8	0.0	5.7	5.7	0.0
CV (%)	20.9	16.6	13.2	0.0	21.1	7.7	0.0
rs [2)]	*-0.308*	*0.053*	*0.314*	-	*0.551*	*-0.552*	-
(Taratara Village)							
11	32.0	32.2	35.8	100	11.4	88.6	100
12	35.0	35.7	29.3	100	23.5	76.5	100
13	41.2	26.8	32.1	100	22.6	77.4	100
14	39.6	24.2	36.2	100	27.9	72.1	100
15	38.6	29.0	32.4	100	23.7	76.3	100
16	42.2	23.4	34.4	100	22.7	77.3	100
17	39.2	26.5	34.3	100	37.5	62.5	100
18	42.7	23.9	33.4	100	46.8	53.2	100
Average	38.8	27.7	33.5	100.0	27.0	73.0	100.0
SD	3.6	4.3	2.2	0.0	10.8	10.8	0.0
CV (%)	9.4	15.7	6.7	0.0	39.8	14.7	0.0
rs [2)]	*0.758**	*-0.751**	*0.228*	-	*0.840***	*-0.840***	-

1) Refer to Table 1. 2) Correlation coefficients with estimated plant age (Table 1). 3) Petiole and leaf sheath. * and **: significant at p<0.05 and p<0.01, respectively

Table 8. Dry matter percentages of a shoot and its organs and parts of sugar palms at different growth stages in Sandabilik and Taratara Villages

Plant No.[1)]	Leaf (%) leaflet	rachis	P+LS[3)]	whole	Trunk (%) bark	pith	whole	Shoot (%)
(Sandabilik Village)								
1	40.7	40.8	30.5	35.8	30.5	16.3	18.1	29.7
2	45.1	36.6	29.1	35.2	34.6	19.4	20.7	28.3
3	45.9	40.1	30.5	36.2	49.2	19.6	24.3	29.7
4	42.8	41.2	29.7	36.0	58.1	30.7	35.7	35.8
5	48.5	43.8	40.1	43.1	63.8	47.3	51.0	48.0
6	43.5	39.8	29.7	36.9	50.3	28.0	32.1	32.9
7	53.5	49.4	45.8	48.5	63.3	47.1	50.9	50.3
8	49.1	43.4	38.4	41.8	60.3	40.2	44.5	44.0
Average	46.1	41.9	34.2	39.2	51.3	31.1	34.7	37.3
SD	4.1	3.8	6.3	4.8	12.8	12.5	13.2	8.8
CV (%)	8.9	9.0	18.5	12.2	24.9	40.3	38.0	23.7
rs [2)]	*0.638*	*0.598*	*0.641*	*0.671*	*0.746**	*0.756**	*0.774**	*0.721**
(Taratara Village)								
11	45.6	38.0	29.1	36.0	22.6	13.2	13.9	28.5
12	45.3	37.9	25.1	34.7	31.2	13.2	15.2	28.3
13	48.1	37.4	21.7	32.8	43.7	25.8	28.4	30.5
14	48.6	39.3	26.9	36.0	54.0	28.4	32.8	34.5
15	45.7	38.3	26.4	35.3	52.9	37.1	39.9	37.9
16	50.2	40.9	25.0	35.9	49.6	30.8	33.7	34.6
17	51.9	48.4	34.8	43.7	50.2	23.2	29.1	33.1
18	52.0	44.3	36.8	44.1	60.2	27.2	36.6	38.6
Average	48.4	40.6	28.2	37.3	45.6	24.9	28.7	33.3
SD	2.8	3.9	5.1	4.2	12.6	8.3	9.5	3.9
CV (%)	5.7	9.6	18.2	11.3	27.7	33.3	33.1	11.8
rs [2)]	*0.856***	*0.821**	*0.614*	*0.751**	*0.884***	*0.630*	*0.787**	*0.783**

1) Refer to Table 1. 2) Correlation coefficients with estimated plant age (Table 1). 3) Petiole and leaf sheath. * and **: significant at $p<0.05$ and $p<0.01$, respectively

of FIs, and then changing to almost same values in SB Village and leaf>trunk in Ta Village. The dry matter percentages of leaf parts increased in the order of leaflet>rachis>petiole and sheath, but those of petioles and sheaths tended to be considerably higher in SB Village than that in Ta Village. The dry matter percentages of the trunk parts changed to bark>pith with an average difference of about 20% in both villages. The shoot dry matter percentage increased from 28–30% in the ETE stage in both villages to 33–50% in SB Village and 33–39% in Ta Village in the dying stage; however, the differences in the shoot dry matter percentage after the emergence stage of FIs were small in both villages.

Discussion

We surveyed changes in the biomass of shoot (leaf, trunk and their parts) with the EPA, using plants from the ETE stage to the dying stage (stage after the sap collection has ended) (SB Village; 5–25 years, Ta Village; 3–16 years) (Table 1). In sugar palms, the trunk formation stage is 3–5 years after seedling, and leaf unfolding is completed after 5–10 years of trunk elongation (Smits, 1996). On average, several FIs emerge from the axil of the uppermost leaf downward, and then MIs follow consecutively and downward; sap is collected with some of these MIs (Smits, 1996). The emergence time and numbers of emerged FIs and MIs, the number of MIs, and the period of sap collected in both villages were reported previously (Yamamoto et al., 2021c). The difference in the years at the same growth stages between the two villages was estimated to be due to differences in the temperature and the soil environment (Mogea et al., 1991; Smits, 1996). Smits (1996) reported that the sugar palm died when the FIs at the apex of the trunk matured, and Mogea et al. (1991) stated that the life span of the sugar palm was 12–20 years. Both villages were located in mountainous areas, and sugar palms were planted and grown on flatlands or lands with various slopes around houses; however, due to differences in the growing environment, biomass production may differ greatly even at the same growth stage and the EPA (Tables 2 and 5). In general, sugar palms growing on flatlands were observed to be better than those growing on sloped lands.

In both villages, the leaf fresh and dry weights increased from the ETE stage to the emergence stage of FIs, reaching the maximum value; the change was small in the early emergence stage of MIs, and then decreased in the dying stage (Tables 2 and 5). The leaf parts showed almost the same changes depending on the EPA with the leaf. As mentioned above, it was presumed to relate to the completion of leaf unfolding at the end of trunk elongation, the decreased number of leaves, and the shortening of upper leaves with the EPA in the inflorescence emergence stage (Yamamoto et al., 2021c). The maximum values of the leaf fresh and dry weights were, respectively, 1756 kg and 757 kg (the early emergence stage of MIs) in SB Village and 1822 kg and 656 kg (the emergence stage of FIs) in Ta Village. The dry weights were 1.4–2.9 times higher than those of Molat in Southeast Sulawesi and Para around Lake Sentani, Papua, which are late-flowering and high-yielding sago palm folk varieties (Yamamoto et al., 2016a, b). And the leaf area of these individuals was also larger than that of sago palm (Yamamoto et al., 2021c). The fresh weight was heavier in the order of petiole and leaf sheath>leaflet>rachis, and the ratios to the shoot fresh weight and leaf fresh weight were also significantly different among them (Tables 2, 3, and 4). However, the dry matter percentage was higher in the order of leaflet>rachis>petiole and leaf sheath (Table 8). As a result, the dry weights and the dry weight ratios of leaf parts were higher in the same order as those of the fresh weight in SB Village; however, in Ta Village, those became higher in the order of leaflet>petiole and leaf sheath>rachis from the emergence stage of FIs (Tables 5, 6, and 7). Comparing the two villages, the dry matter percentage of the petiole and leaf sheath was lower in Ta Village than in SB Village throughout the growing period. As a result, the tendency of the dry weight of the petiole and leaf sheath was opposite of that of fresh weight and higher in SB Village than in Ta Village. The cause of this was not clear, but it is necessary to examine it from the viewpoint of genetic differences and environmental factors in sugar palms between both villages. The leaflet dry matter percentage was almost the same as that in the sago palm, but those of the rachis and the petiole and leaf sheath were much lower than those of the sago palm (Yamamoto et al., 2016a). The difference in the dry matter percentages of leaf parts is considered to be related to the photosynthetic function of leaves, the movement of photosynthetic products from leaflet through rachis and petiole and leaf sheath, and the water-conducting ability.

The fresh and dry weights of the shoot and the trunk tended to increase with the EPA in both villages (Tables 2 and 5). This result agreed with those of sago palms (Yamamoto et al., 2016a). However, in the sugar palm, the change after the emergence stage of FIs was small, as was clearly seen in Ta Village. The maximum values of fresh (dry) weights of the shoots were 4543 (2179) kg and of the trunks were 2787 (1423) kg in the early emergence stage of MIs in SB Village, and 3317 (1146) kg (shoots) and 1856 (625) kg (trunks) during the period from the emergence stage of FIs to the early emergence stage of MIs in Ta Village, respectively. The differences in the maximum values of the shoot and the trunk weights between the two villages were larger than those of the above-mentioned leaf weights. The cause of this difference is not clear, but it is estimated that there are differences in temperature and soil factors depending on the location conditions of SB and Ta Villages. Furthermore, in addition to this, the involvement of genetic differences in sugar palms between the two villages and/or within each village is also considered. Comparing the shoot and the trunk weights of these sugar palms with the maximum values of Para and Molat mentioned above, the shoot fresh weight of sugar palms was superior to that of Molat (3050 kg) but inferior to that of Para (5000 kg) in both villages (Yamamoto et al., 2016a, b). In addition, the shoot dry weights in SB Village and Ta Village were almost equal and inferior to that of Para (2200 kg), respectively, although those in both villages were superior to that of Molat (1030 kg). The maximum dry weight of trunks was inferior to that of Para (1700 kg) in both villages, but those in SB Village and Ta Village were twice and considerably lower than that of Molat (740 kg), respectively. Similar to the trunk, the fresh and dry weights of the bark and the pith also tended to increase with the EPA (Tables 2 and 5). The fresh and dry weights of the pith were heavier than those of the bark, whereas the dry matter percentage was higher in the bark than in the pith irrespective of the growth stage (Table 8). Yamamoto et al. (2016a) reported similar results for sago palms. Regarding the dry matter percentages of the bark and the pith, both the sugar palm and the sago palm had higher values with increasing the EPA. However, the difference between the two parts decreased with increasing the EPA in the sago palm, whereas in the sugar palm, the difference between the two parts remained 10–30% depending on the growth stage. The maximum dry matter percentage of the bark was 40–45% for the sago palm and 50–60% for the sugar palm. In the sugar palm, a tough, fibrous, and dark brown tissue developed with increasing the EPA on the outer periphery of the pith (Yamamoto et al., 2021b). Due to the development of the bark and the increase in the dry matter percentage, the fresh and dry weight ratios of the bark and the pith to the trunk weight increased and decreased with the EPA, respectively, and the pith weight ratio was lower in dry weight than in fresh weight (Tables 4 and 7). In addition, the dry matter percentage of the pith of sugar palms did not show a clear tendency to increase with the EPA as seen in sago palms, indicating that the numbers of emerged FIs and MIs and fruit development on the FIs, the time when sap was first collected, the length of sap collection, and so forth may affect the percentage.

Mogea et al. (1991) and Smits (1996) found that the optimum harvest time for starch production in the sugar palm was from FI differentiation to flowering, and Yamamoto et al. (2021b, c) suggested that the optimum harvest time was around the emergence stage of the first FI. According to the results of Yamamoto et al. (2021c), based on the same materials as used in this study, high starch contents were found in the plants during the emergence of FIs to the early emergence stage of MIs before sap collection was started or immediately after its start. Looking at the fresh and dry weight ratios of the trunk to the shoot weight at this time as a harvest time, the ratios in both villages were in the ranges of 45–60% and 45–65%, respectively. The dry weight ratio was slightly higher because of the dry matter percentage. This trunk dry weight ratio was lower than that of 70–75% of sago palms at the optimum harvest stage (Yamamoto et al., 2016a). In addition, the fresh and dry weight ratios of the pith to the shoot (trunk) weight of sugar palms at this time in both villages were in the ranges of 40–50 (80–85) % and 30–45 (70–80) %, respectively. Compared to the sago palm's about 60 (80–85) % fresh weight and approximately 60 (80) % dry weight (Yamamoto et al., 2016a), the fresh and dry weight ratios to the shoot of the sugar palm were considerably lower but those ratios to the trunk were equal or slightly lower than those of the sago palm.

As mentioned above, in both villages, the fresh and dry weights of the shoot and the trunk tended to increase with the EPA, but changes after the emergence stage of FIs tended to be small. On the other hand, leaf fresh and dry weights increased from the ETE stage to the emergence stage of FIs and reached the maximum value; the change was small in the early emergence stage of MIs and then decreased toward the dying stage. The leaf and trunk weight ratios to the shoot weight decreased and increased in both the fresh and dry weights with the EPA, respectively; both ratios were almost equal in the emergence stage of FIs. However, due to the large variation in the maximum trunk weight of both villages and between individuals of the same growth stage in SB Village, it is necessary to clarify the genetic difference of sugar palms in both villages and the effects of growing environments on the biomass production and starch yield. Additionally, in this study, we investigated the biomass of leaves and trunks of sugar palms excluding FIs and MIs, but surveys including them will be necessary in the future. However, since there are large differences among plants in the numbers of emerged FIs and MIs and in the development of fruits on the FIs, investigating the uniform development of inflorescences and fruits is considered to be extremely difficult. In addition, the presence or absence of sap collection, the number of MIs from which sap is collected, the sap collection period, and so forth are considered to affect the production of dry matter. These points should be also considered in future research.

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