Effect of Variety and Stage of Maturity on Nutritive Value of Whole Crop Rice, Yield, Botanical Fractions, Silage Fermentability and Chemical Composition

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ABSTRACT : The effect of eight varieties of grain and forage type whole crop rice (*Oryza sativa* L *Japonica*) each harvested at four stages of maturity were investigated for morphology and yield, proportion of botanical fractions, fermentatability and chemical composition in an 8×4 factorial experiment. All crops were sown in 1997 at Saitama Prefecture, Japan under identical condition and harvested on 10, 22, 34 and 45 days after flowering in 1998. Total DM yield of forage type varieties was similar to that of the highest yield of grain type varieties. However, while yield of forage type varieties was attributed to higher proportion of straw than head, the reverse was in the case of grain type varieties. Yield in line with the proportion of head increased ($p<0.001$), but in contrast proportion of straw decreased ($p<0.001$) with the increase in maturity. Silage fermentability of grain type varieties was better than forage type varieties. Fermentability improved with the increase ($p<0.001$) in maturity suggesting that the moisture content should be reduced to improve fermentation quality. Forage type varieties contained higher ($p<0.001$) ash, crude fat (EE), organic cell wall (OCW) and acid detergent fiber (ADF), but contained lower crude protein (CP), organic cell content (OCC), CP in OCC and nitrogen-free cell wall extract (NCWFE) than the grain type varieties. The ash, CP, EE, Oa (60% digestible OCW), Ob (40% digestible OCW), OCW, ADF and acid detergent lignin (ADL) decreased ($p<0.001$), but OCC and NCWFE increased ($p<0.001$) with the increase in maturity. It is concluded that stage of maturity not only increases yield and proportion of head, but also improved the fermentation quality and increases quality chemical composition (except CP) of whole crop rice. Forage type varieties may be as good as grain type varieties in terms of yield, but fermentation quality and chemical composition may not be as good as that of grain type varieties. ***(Asian-Aust. J. Anim. Sci. 2004. Vol 17, No. 2 : 183-192)***

Key Words : Whole Crop Rice, Grain Variety, Forage Variety, Yield, Nutritive Value

INTRODUCTION

The whole crop rice (WCR: *Oryza sativa* L *Japonica*) as a feed for ruminants is being offered in some parts of Kanto and Kyushu areas and it is likely that the changing society and economic pressure will result in farmers eventually using it as a feed for ruminants throughout Japan. In Japan, about one-third of the total cultivable land are being set-aside which is a potential loss for the economy and environment of the country. Presently, 14% of the total digestible nutrient requirements of dairy cattle is coming from commercial (imported) forages (Agriculture. Forestry and Fisheries Research Secretariat. 1994). which would be higher if other species of animals are taken into consideration. Growing WCR as feed in these set aside land would be a step forward towards self-sufficiency in feed.

Although there has been some research to elucidate the utilization of WCR (Yahara et al., 1981; Hara et al., 1986; Nakui et al., 1988). or the factors that affect yield and nutritive value (Yoshida et al.. 1984). no research has been undertaken on the effect of variety and stages of maturity on yield or nutritive value in relation to the grain or forage type WCR. Proportion of head in whole crop cereals (WCC) is homologous to yield when stage of maturity is considered as a factor since both proportion of head and yield increases with the increase in maturity (Yoshida et al.. 1987a,b; Nakui et al.. 1988). Adamson and Reeve (1992) reported that a change in grain to straw ratio in WCC from 50:50 to 60:40 represents an increase in metabolizable energy of 0.8 MJ kg^{-1} dry matter (DM). Therefore. proportion of head in WCC may be regarded as an indicator for both yield and nutritive value. Because forage type varieties are taller than grain types, it is assumed that the former may have lower proportion of head and consequently lower yield and nutritive value. In contrast, opposite views also exist that the nutritive value of forage type varieties may be higher than grain type varieties since more grain of grain type varieties may pass through the feces. which lowers nutritive value. However. there is no data on this aspect, which deserves more research.

Previous reports suggest that the fermentability of WCR is not good especially at early stages of maturity when moisture content of such crops is high. Similarly, ensiling at a more mature stages are less digestible (Harley. 1981). low water-soluble carbohydrate (Tetlow and Mason. 1987a). prone to rapid fermentation when silos are open (Woolford et al.. 1982) and crops are resilient and require more oxygen

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Table 1. Effect of variety and stage of maturity on yield and morphological characteristics of whole crop rice

Variety (V)	Maturity (M)	Harvest date†	Harvested, DAF‡	Plant height, cm	Stem length, cm	Head length, cm	No. head, m^{-2}	DM%	Yield, t DM ha^{-1}
Akichikara	MS1	Aug-10	11	101	78	20.5	348	24.3	9.7
	MS2	Aug-19	20	100	76	21.0	333	25.0	10.6
	MS3	Aug-27	28	101	78	19.0	426	35.4	12.5
	MS4	Sept-8	40	108	79	20.7	340	36.1	12.4
Fukuhibiki	MS1	Aug-6	10	97	76	19.4	337	22.7	7.9
	MS2	Aug-17	21	96	74	19.4	263	29.1	10.7
	MS3	Aug-26	30	101	79	19.8	389	35.1	12.0
	MS4	Sept-4	39	102	77	21.2	300	40.2	12.0
Habataki	MS1	Aug-11	10	116	92	25.3	281	23.5	11.3
	MS2	Aug-24	23	113	88	25.7	289	29.5	12.6
	MS3	Sept-4	34	112	84	24.9	259	32.6	13.7
	MS4	Sept-17	47	114	86	26.2	285	35.6	15.7
Hokuriku168	MS1	Aug-13	10	119	90	22.4	326	24.4	10.4
	MS2	Aug-25	22	118	88	22.4	263	28.1	11.2
	MS3	Sept-8	36	115	80	22.6	259	30.8	12.4
	MS4	Sept-17	45	119	90	22.4	255	37.6	12.9
Tamakei 96	MS1	Aug-14	10	116	91	19.9	375	20.3	9.7
	MS2	Aug-26	22	118	88	21.0	329	26.8	12.0
	MS3	Sept-8	35	113	90	20.0	352	28.6	12.2
	MS4	Sept-17	44	117	89	20.6	340	33.8	13.1
Yumetoiro	MS1	Aug-16	10	105	79	25.2	348	22.9	11.9
	MS2	Aug-27	21	104	83	25.4	322	26.8	12.3
	MS3	Sept-9	34	106	84	25.8	322	35.0	16.0
	MS4	Sept-17	42	110	85	25.3	289	27.8	15.1
Hamasari	MS1	Sept-9	9	127	90	20.3	329	20.2	10.7
	MS2	Sept-22	22	123	95	19.0	355	23.2	12.1
	MS3	Oct-2	32	131	93	19.2	329	24.7	14.3
	MS4	Oct-15	45	120	93	19.4	307	34.7	14.7
Kusanami	MS1	Sept-9	11	132	93	21.2	296	22.2	11.4
	MS2	Sept-22	25	130	90	20.6	355	25.0	12.8
	MS3	Oct-2	35	134	96	21.9	337	27.0	14.6
	MS4	Oct-15	48	125	92	19.8	333	38.1	16.1
		V		93***	86***	94***	52**	15**	36***
		M		ns	ns	ns	ns	74***	57***
		V×M		ns	ns	ns	40**	ns	ns

†Harvested in 1998; MS1, MS2, MS3 and MS4 are maturity stages at harvest means harvesting on 10, 22, 34 and 45 days after flowering respectively; ‡DAF=harvested on days after flowering; *** $p<0.001$, ** $p<0.01$, NS: not significant ($p>0.05$).

infiltration (Ohyama et al., 1975; Ruxton et al., 1975). WCR contains high moisture even at a mature stage. Botanical fractions, chemical composition and fermentability are the primary indication of nutritive value of forages, which may be affected by the variety and stages of maturity. Therefore, the physical and chemical quality of WCR as a feed for ruminants needs to be assessed to understand the variations in their nutritive value.

The present study was therefore undertaken to investigate the effect of variety and stages of maturity on morphology and yield, proportion of botanical fractions, fermentation quality and chemical composition of WCR.

MATERIALS AND METHODS

Site description, variety, agronomy and ensiling

Eight varieties of rice (*Akichikara, Fukuhibiki, Habataki, Hamasari, Hokuriku 168, Kusanami, Tamakei 96 and Yumetoiro*) were sown into prepared seedbeds at Saitama, Japan in 1997 and the forage harvested in 1998. Each variety at each stage of maturity was sown in two plots; each of the plots was 3×2 m^2. Two of the varieties, Hamasari and Kusanami, were developed by the breeders as forage type, which are generally characterized by their long stems. Others were considered grain varieties because they usually produce higher grain yields and have longer stems. Total nitrogen, phosphorous and potassium was applied at 130, 100 and 130 kg ha^{-1} respectively on all crops. Fungicide, herbicide and insecticide were applied at the same rate. Crops were irrigated intensively in all cases. Each variety was harvested on an average at set periods once flowering commenced e.g. approximately at 10 (MS1), 22 (MS2), 34 (MS3) and 45 (MS4) days after flowering. The day of flowering was considered when 50% of the crop

Table 2. Main effect means of effect of variety and maturity on yield and morphological characteristics of whole crop rice silage

Treatments	Subclass	n	Plant height, cm	Stem length, cm	Head length, cm	No. of head, m^{-2}	DM%	Yield, t DM ha^{-1}
Variety	Akichikara	4	103^{de}	78^{d}	20^{de}	362^{a}	30.2^{ab}	11.3^{bc}
	Fukuhibiki	4	99^{e}	77^{d}	20^{de}	322^{ab}	31.8^{a}	10.7^{c}
	Habataki	4	114^{c}	88^{b}	26^{a}	279^{bc}	30.3^{ab}	13.3^{a}
	Hokurku 168	4	118^{c}	87^{b}	22^{b}	276^{c}	30.2^{ab}	11.7^{b}
	Tamakei 96	4	116^{c}	90^{ab}	20^{de}	349^{a}	27.4^{bc}	11.7^{b}
	Yumetoiro	4	106^{d}	83^{c}	25^{a}	320^{abc}	28.1^{abc}	13.8^{a}
	Hamasari	4	125^{b}	93^{a}	19^{d}	330^{a}	25.7^{c}	13.0^{a}
	Kusanami	4	130^{a}	93^{a}	21^{c}	330^{a}	28.1^{abc}	13.7^{a}
Stages of maturity¯	MS1	8	114	86	22	330	22.6^{d}	10.4^{c}
	MS2	8	113	85	22	314	26.7^{c}	11.8^{b}
	MS3	8	114	86	22	334	31.2^{b}	13.5^{a}
	MS4	8	114	86	22	306	35.5^{a}	14.0^{a}

¯ MS1, MS2, MS3 and MS4 as described in Table 1.

$^{a, b, c, d, e, f, g}$ values with different superscripts in a column within the same subclass differ (p<0.001 to 0.01).

Table 3. Effect of variety and stage of maturity on proportions of botanical fractions of whole crop rice silage

Variety (V)	Stages of maturity (M)¯	Proportion (% DM)			
		Leaf blade	Leaf sheath	Stem	Head
Akichikara	MS1	32	31	17	20
	MS2	24	26	13	38
	MS3	20	22	11	47
	MS4	17	21	11	51
Fukuhibiki	MS1	30	34	17	19
	MS2	22	24	13	42
	MS3	18	20	11	51
	MS4	15	20	11	54
Habataki	MS1	33	30	15	22
	MS2	20	20	10	50
	MS3	19	18	9	54
	MS4	14	17	9	60
Hokuriku 168	MS1	36	35	16	14
	MS2	25	25	14	36
	MS3	19	21	11	49
	MS4	17	21	11	51
Tamakei 96	MS1	38	32	16	14
	MS2	27	26	13	34
	MS3	23	22	11	45
	MS4	18	21	11	50
Yumetoiro	MS1	32	27	14	26
	MS2	24	19	11	46
	MS3	21	18	10	52
	MS4	16	18	9	58
Hamasari	MS1	21	19	54	7
	MS2	31	28	12	29
	MS3	25	25	11	38
	MS4	21	25	13	41
Kusanami	MS1	27	28	13	32
	MS2	27	28	14	30
	MS3	25	25	13	37
	MS4	22	24	15	39
	V	7***	18***	21***	16***
	M	68***	50***	25***	76***
	V×M	25***	33***	54***	8***

¯ MS1, MS2, MS3 and MS4 are as described in Table 1. *** p<0.001.

was showing inflorescence.

Immediately after harvesting, the biomass (5 to 6 kg) at each stages of maturity was ensiled in triplicates (per plot) in polythene bags. After packing the bag with WCR, a

Table 4. Main effect means of effect of variety and stage of maturity on botanical fractions of whole crop rice silage

Treatments	Subclass	n	Proportion (% DM)			
			Leaf blade	Leaf sheath	Stem	Head
Variety	Akichikara	20	23^{c}	25^{bc}	13^{bc}	39^{c}
	Fukuhibiki	20	21^{d}	25^{bc}	13^{bc}	42^{b}
	Habataki	20	21^{d}	21^{d}	11^{c}	47^{a}
	Hokuriku 168	20	24^{bc}	26^{b}	13^{bc}	37^{d}
	Tamakei 96	20	26^{a}	25^{bc}	13^{bc}	36^{de}
	Yumetoiro	20	23^{c}	20^{d}	11^{c}	46^{a}
	Hamasari	20	24^{bc}	24^{c}	23^{a}	29^{f}
	Kusanami	20	25^{b}	27^{a}	14^{b}	35^{e}
Stages of maturity*	MS1	40	31^{a}	29^{a}	20^{a}	19^{d}
	MS2	40	25^{b}	25^{b}	12^{b}	38^{c}
	MS3	40	21^{c}	21^{c}	11^{b}	47^{b}
	MS4	40	17^{d}	21^{c}	11^{b}	50^{a}

* MS1, MS2, MS3 and MS4 described in Table 1.

a, b, c, d, e, f values with different superscripts in a column within the same subclass differ ($p<0.001$).

pump (Fuji Impulse, Japan) was used to reduce the insides air from the bags and sealed. Samples were removed between 45 and 49 days after preparation. After taking samples for botanical fractionation, all remaining silages were chopped (Yamamoto P-156, Japan) to smaller sizes (8-12 cm in length). Replicates (triplicates from each plot) of each variety at each stage of maturity were thoroughly mixed and composited after chopping. DM was determined (at 100°C for 24 h) from the composite sample. All chopped samples stored at -18°C awaited further processing.

Yield and morphology

A scale was used to measure the data on plant height (cm), straw and head lengths (cm) at the time of harvest. Number of head (per m^2) was also counted. The plot was harvested manually by a sickle. A portion (200 g) of sample was taken to determine the DM at 100°C for 24 h. Total biomass yield (t ha^{-1}) was determined on DM basis.

Botanical fractions

Five (2 plots×3 sub-reps=6; but one sub-replicate was preserved in case of long term need), 300 WCR from each variety at each stage of maturity were sampled immediately after opening the silo bags and fractionated manually into four fractions; leaf blade, leaf sheath, stem and head. Each fraction was then weighed into a pre-dried (60°C for 48 h) and pre-weighed envelope, and dried for 60°C for 48 h. Proportion of botanical fractions was calculated as %DM.

Fermentation quality of silage

Twenty-five grams of fresh silage sample after chopping (8-10 cm) from each variety and each stage of maturity was mixed with 75 g of water in a beaker. The liquid was then filtered through two layers of cheesecloth. The pH was then determined with a pH meter (Horiba, ex-20, Kyoto, Japan) on samples obtained after filtration. The organic acid contents (lactic, acetic, propionic and butyric) were measured by HPLC using the method of Ohmomo et al. (1993); (column: Sodex RS Pak KC-811; detector: JASCO 875 UV, 450 nm; eluent: 3 mM $HClO_4$ 1.0 ml min^{-1}; reagent: 0.2 mM Bromothymol blue+8 mM Na_2HPO_4+ 2mM NaOH, 1.0 ml min^{-1}; temp: 60°C).

Chemical composition of silage

Chopped silage samples (8-10 cm) from each variety and each stage of maturity were dried at 60°C, milled through 1 mm screen and analyzed in duplicate for DM, ash, crude protein (CP), crude fat (EE) (AOAC, 1980); Oa (60% digestible OCW), Ob (40% digestible OCW), organic cell wall (OCW), organic cell content (OCC), CP in OCC and nitrogen-cell wall free extract (NCWFE) (Abe et al., 1979; Abe, 1988), and acid detergent fiber (ADF), acid detergent lignin (ADL), acid detergent insoluble nitrogen (ADIN) (Van Soest et al., 1991).

Statistical analysis

Data on the effect of variety (8) and stage (4) of maturity were analyzed by SAS using general linear model procedure (SAS, 1988) in an 8×4 factorial experiment with replications varied from 2 (in all cases except for botanical fractions) to 5 (for botanical fractions) depending on the parameters which includes 8 variety at 4 stages of maturity. The statistical model was as follows:

$$Y_{ijk}=\mu+V_i+M_j+S_k+(V\times M)_{ij}+E_{ijk}$$

Where, Y_{ijk}=dependent variable, μ=population mean, V_i=average effect of variety i (i=8), M_j=average effect of maturity stage j (j=4), S_k=average effect of replication k; $(V\times M)$ ij=average effect of interaction of variety i and maturity j, and E_{ijk}=residual error, assumed to be normally, identically and independently distributed. Main effect means were tested by the least square difference (SAS, 1988).

Table 5. Effect of variety and stage of maturity on fermentation characteristics of whole crop rice silage

Variety (V)	Stages of maturity (M)[-]	Contents of acids in silage, DM%				pH
		Lactic	Acetic	Propionic	Butyric	
Akichikara	MS1	0.00	4.86	1.10	1.45	4.68
	MS2	0.27	3.88	0.68	1.20	3.75
	MS3	0.00	1.59	0.11	0.35	5.09
	MS4	2.71	0.99	0.10	0.23	4.28
Fukuhibiki	MS1	0.19	4.23	0.90	1.05	4.71
	MS2	0.00	2.86	0.66	0.74	4.10
	MS3	0.11	1.58	0.13	0.39	4.99
	MS4	0.87	0.68	0.13	0.00	4.80
Habataki	MS1	0.00	5.47	1.06	1.48	4.62
	MS2	0.08	2.41	0.50	0.88	4.08
	MS3	0.03	1.87	0.14	0.59	4.97
	MS4	1.55	1.04	0.07	0.33	5.14
Hokuriku 168	MS1	0.00	3.72	0.37	0.98	4.80
	MS2	0.47	2.08	0.39	0.51	4.30
	MS3	0.08	1.86	0.34	0.61	4.79
	MS4	0.68	1.75	0.06	0.61	5.09
Tamakei 96	MS1	0.00	5.58	1.24	1.48	4.71
	MS2	0.00	3.14	0.52	0.81	4.73
	MS3	0.06	2.25	0.15	0.55	4.78
	MS4	0.00	0.10	0.00	0.00	7.21
Yumetoiro	MS1	0.00	4.76	1.01	1.38	4.72
	MS2	0.00	2.55	0.53	0.70	4.26
	MS3	0.05	0.01	1.63	0.18	5.31
	MS4	0.00	0.04	0.02	0.24	7.39
Hamasari	MS1	0.00	4.33	0.33	1.33	4.60
	MS2	0.05	2.47	0.27	0.74	4.61
	MS3	0.22	2.99	0.54	0.80	4.40
	MS4	0.05	1.24	0.00	0.43	4.86
Kusanami	MS1	0.00	5.07	0.53	1.76	4.47
	MS2	0.19	2.59	0.30	0.86	4.44
	MS3	0.05	2.66	0.37	0.86	4.42
	MS4	0.07	0.76	0.00	0.23	4.99
	V	19***	ns	15**	6*	22***
	M	28***	84***	45***	80***	35***
	V×M	53***	12***	40***	13***	43***

[-] MS1, MS2, MS3 and MS4 are as described in Table 1. *** $p<0.001$, ** $p<0.01$, * $p<0.05$.

RESULTS

Yield and morphological characteristics

Morphological characteristics were affected by the variety ($p<0.001$; except number of head, $p<0.01$), but not affected ($p>0.05$) by the plants stages of maturity (Table 1). Forages from grain varieties contained higher ($p<0.001$) DM (except Tamakei 96) than the forage varieties, but DM yield of forage type varieties were as high as the highest yield of grain varieties. Both DM content and DM yield increased ($p<0.001$) with the increase in maturity, but there was no interaction effect ($p>0.05$) on yield (Table 2).

Proportion of botanical fractions

All botanical fractions were affected ($p<0.001$) by both variety and stages of maturity, and their interactions (Table 3). Forage varieties generally contained higher proportion of stem and straw (leaf plus stem), but lower proportion of head than the grain varieties. Increase in maturity at harvest decreased the proportion of leaf blade, leaf sheath and stem but increased head. This increase or decrease in proportions of botanical fractions was more or less marked in grain varieties than in forage varieties (Table 4). Stage of maturity was responsible for most of the variations accounted for by the treatments for botanical fractions (Table 3), suggesting that stage of maturity is the most important factor in regulating the proportion of botanical fractions.

Ensiling characteristics

Organic acid contents and pH differed ($p<0.001$; except butyric acid, $p<0.05$; acetic acid, $p>0.05$) between varieties (Table 5). Organic acid contents and pH differed ($p<0.001$) due to the stages of maturity. In general, lactic and propionic production was higher, but butyric acid production was lower in grain varieties than forage varieties.

Table 6. Main effect means of the effect of variety and stage of maturity on fermentation characteristics of whole crop rice silage

Treatment	Subclass	n	Concents of acids in silage, DM%				pH
			Lactic	Acetic	Propionic	Butyric	
Variety	Akichikara	4	0.745[a]	2.83	0.50[ab]	0.81[ab]	4.45[b]
	Fukuhibiki	4	0.293[ab]	2.34	0.46[ab]	0.55[b]	4.65[ab]
	Habataki	4	0.415[ab]	2.70	0.44[ab]	0.82[ab]	4.70[ab]
	Hokuriku 168	4	0.308[ab]	2.35	0.29[b]	0.68[ab]	4.75[ab]
	Tamakei 96	4	0.015[b]	2.77	0.48[ab]	0.71[ab]	5.36[a]
	Yumetoiro	4	0.013[b]	1.84	0.80[a]	0.63[ab]	5.42[a]
	Hamasari	4	0.080[ab]	2.76	0.29[b]	0.83[ab]	4.62[ab]
	Kusanami	4	0.078[ab]	2.77	0.30[b]	0.93[a]	4.58[ab]
Stages of maturity*	MS1	8	0.024[b]	4.75[a]	0.82[a]	1.36[a]	4.66[b]
	MS2	8	0.133[b]	2.75[b]	0.48[b]	0.81[b]	4.28[b]
	MS3	8	0.075[b]	1.85[c]	0.43[b]	0.54[c]	4.84[b]
	MS4	8	0.741[a]	0.83[d]	0.05[c]	0.26[d]	5.47[a]

* MS1, MS2, MS3 and MS4 described in Table 1.
a, b, c, d values with different superscripts in a column within the same subclass differ ($p<0.001$ to 0.05).

Increase in maturity increased lactic acid, but decreased acetic, propionic and butyric acid of WCR (Table 6). There was significant ($p<0.001$) interaction between variety and stage of maturity for all studied organic acid contents and pH.

Chemical composition

All chemical constituents (% DM) of WCR differed ($p<0.001$) due to the variety and stages of maturity, and their interaction (Table 7). Forage varieties contained higher ash, EE, Ob, OCW, ADF, but lower CP, Oa, ADIN, OCC, CP in OCC and NCWFE than the grain varieties. Increase in maturity increased OCC and NCWFE, but decreased ash, CP, EE, Oa, Ob, OCW and ADF (Table 8).

DISCUSSION

The DM content of WCR used in the present study was similar to that reported by Fukumi et al. (1979), but was slightly lower than those reported by other workers (Yahara et al., 1981; Hara et al., 1986). The lower DM content of WCR in the present study may be due to the fact that these forages were grown under intensive irrigation management system and partly because of the heavy rainfall (on average 1,250 mm) during the growing period. Although relationships were not significant ($p>0.05$), positive relationships between yield and stem length ($Y=0.104X+3.479$; $R^2=0.12$; $r=0.35$; $n=32$), or head length ($Y=0.268X+6.560$; $R^2=0.11$; $r=0.33$; $n=32$) indicating that there may be a possibility to increase yield either by increasing length of the stem or head, or by both. For example, Habataki and Yumetoiro both have longer head and shorter stem have the highest yield. On the other hand, forage varieties have longer stem but shorter head also have the highest yield. Fukuhibiki neither had longer stem nor had longer head, which may lead to its lowest yield. The results therefore suggest that the yield may be increased either by increasing length of the stem or head, or by both. However, although yield can be increased either by manipulating both stem or head, their effects on the nutritive value needs to be known before such manipulation. The DM yield (t ha^{-1}) of WCR used in the present study was much higher than those reported by Yahara et al. (1981), but was only slightly higher to those reported by Nakui et al. (1988). The higher DM yields in the present study may be due to the fact that relatively newer varieties released by the breeders were used in the present study compared to the older varieties used by others. Stage of maturity was the key factor in determining both DM content and yield because maturity accounted for most of the variation than by the variation accounted for by the variety (Table 1). Forage varieties were taller than grain type varieties possibly because of the longer stem of the former than the latter types of varieties. Grain type varieties, on the other hand, had longer head.

The results (Table 3) suggest that with aging while proportion of leaf blade continues to decrease, head on the other hand continues to increase. Proportion of both leaf sheath and stem on the other hand decreased from MS1 to MS2, they (leaf sheath and stem) become stable from MS3 to MS4. This suggests that with maturity, proportion of head increased at the expense of proportion of leaf blade rather than leaf sheath and stem. Stages of maturity were also responsible for most of the variation accounted for by than the effect of variety (Table 3). However, the effect of variety on botanical fractions cannot be ruled out as its effect was masked by the interaction, which accounted for a significant variation. The marked increase in proportion of head and decrease in straw fractions (leaf plus stem) from MS1 to MS2 particularly in grain varieties is probably due to the formation of grain during that period. The decrease and increase in proportion of straw and head respectively with maturity, on the other hand, was less pronounced in forage varieties than grain varieties. It is likely that

Table 7. Effect of variety and stage of maturity on chemical composition (%DM) of whole crop rice silage

Variety (V)	Maturity (M)[†]	Ash	CP	EE	Oa	Ob	OCW	ADF	ADL	ADIN	OCC	CP in OCC	NCWFE
Akichikara	MS1	14.2	8.7	2.13	19.5	45.5	65.0	42.4	7.3	1.36	14.4	6.8	5.4
	MS2	12.9	8.3	2.66	16.5	38.7	55.3	35.6	6.9	1.21	25.5	6.4	16.5
	MS3	10.6	7.8	1.89	11.3	34.0	45.4	28.7	5.5	1.21	39.4	6.0	31.6
	MS4	11.3	8.1	2.15	10.6	34.0	44.5	27.6	5.8	1.21	39.8	6.2	31.4
Fukuhibiki	MS1	14.6	9.3	1.86	6.1	58.2	64.4	40.7	5.9	1.55	14.8	7.3	5.6
	MS2	12.3	8.3	2.29	4.4	45.7	50.1	30.8	5.2	1.34	31.3	6.5	22.5
	MS3	11.0	7.9	1.67	3.9	38.2	42.1	28.8	5.0	1.33	43.0	6.1	35.3
	MS4	10.4	7.9	1.64	0.5	38.6	39.1	27.3	6.0	1.37	46.6	6.1	38.9
Habataki	MS1	17.1	10.0	1.92	7.1	52.3	59.3	40.7	6.2	1.50	17.2	8.0	7.2
	MS2	12.6	9.0	2.09	13.8	29.1	42.9	29.6	6.1	1.48	37.9	7.1	28.8
	MS3	12.4	8.5	2.14	13.7	30.4	44.1	29.6	6.3	1.60	39.5	6.6	30.7
	MS4	11.2	9.0	1.72	9.0	27.8	36.9	24.4	5.9	1.79	47.9	7.1	39.1
Hokuriku	MS1	15.2	8.8	1.93	20.3	44.4	64.7	42.1	5.6	1.09	13.6	6.9	4.7
	MS2	13.3	8.5	2.26	4.5	50.4	54.9	34.9	5.2	1.13	25.5	6.6	16.6
	MS3	11.4	7.4	1.80	2.2	43.2	45.3	29.6	5.0	1.44	39.2	5.7	31.8
	MS4	10.9	7.5	2.04	1.5	40.4	42.0	27.2	4.7	1.37	42.8	5.7	35.0
Tamakei	MS1	16.3	8.9	2.05	22.2	46.2	68.4	41.1	5.6	1.26	8.8	7.0	0.0
	MS2	13.9	8.5	2.36	5.1	51.6	56.7	30.4	5.6	1.13	22.3	6.7	13.3
	MS3	12.6	7.8	1.75	1.7	45.4	47.1	26.9	7.4	1.24	35.8	6.0	28.1
	MS4	15.2	9.2	1.55	0.1	44.4	44.5	26.8	7.6	2.18	35.7	7.3	26.9
Yumetoiro	MS1	18.2	9.1	1.94	8.5	52.6	61.1	40.5	6.2	1.36	14.7	7.2	5.6
	MS2	14.4	8.3	2.08	5.0	41.0	46.0	29.4	6.0	1.22	33.6	6.5	25.0
	MS3	12.9	8.4	1.80	5.9	36.6	42.5	29.6	6.3	1.15	40.3	6.5	32.0
	MS4	15.9	9.7	1.24	0.0	36.8	34.7	24.3	5.9	2.09	45.9	7.7	37.0
Hamasari	MS1	17.5	8.1	2.15	6.6	59.7	66.3	38.9	6.0	1.48	11.9	6.3	3.5
	MS2	14.4	7.2	2.39	5.3	50.7	56.0	34.8	6.7	1.24	25.3	5.5	17.5
	MS3	13.6	6.8	2.16	3.1	47.4	50.5	28.7	5.0	1.15	32.0	5.1	24.7
	MS4	12.8	7.2	1.92	0.9	47.2	48.1	27.8	6.1	1.20	33.4	5.5	26.1
Kusanami	MS1	16.2	7.5	1.88	6.5	59.1	65.5	41.3	7.1	1.27	14.4	5.7	6.8
	MS2	13.9	7.3	2.50	3.7	50.1	53.8	35.5	6.8	1.14	26.2	5.6	18.1
	MS3	13.0	7.1	2.26	4.5	45.0	49.5	29.9	5.2	1.23	29.9	5.4	22.2
	MS4	12.9	6.9	1.91	4.2	44.8	49.0	27.8	6.1	1.17	32.7	5.2	25.6
	V	30***	62***	25***	36***	41***	14***	4***	37***	25***	11***	62***	9***
	M	58***	23***	50***	29***	40***	82***	92***	7***	21***	85***	23***	86***
	V×M	12***	15***	25***	35***	19***	3***	5***	57***	53***	4***	15***	5***

[†] MS1, MS2, MS3 and MS4 are as described in Table 1. *** p<0.001.
CP=crude protein, EE=ether extract, OCW=organic cell wall, Oa=(60% digestible OCW), Ob=(40% digestible OCW), ADF=acid detergent fiber, ADL=acid detergent lignin, ADIN=acid detergent insoluble nitrogen, OCC=organic cell content, NCWFE=nitrogen free cell wall extract.

mobilisation of solubles from the stem or leaf to form grain is more pronounced in grain varieties, which is reduced in forage varieties due to their lower yield of grain.

The proportion of head in forage varieties (Hamasari and Kusanami) in the present study was lower than those reported by Yoshida et al. (1987b) at similar stages of maturity. The proportion of head in grain varieties although was lower than that reported by Yahara et al. (1981), was similar to those reported by others (Hara et al., 1986; Nakui et al., 1988). The lower proportion of head, if any, in the present study may be because the botanical fractionation was done in ensiled crops while those in the literature was done before ensiling explains the reasons for differences. The differences may be because the fractionation in this study was done in ensiled crops as compared in crops before ensiling. Biomass and proportion of head both increased with maturity conferred with many types of forages.

Silage fermentability of WCR as indicated by lactic acid production was poor. This finding is in line with literature (Yahara et al., 1981; Nakui et al., 1988). In general, lactic acid production was higher in grain varieties than in forage varieties possibly because of the higher DM content (mainly sugars and starch) of the former than the latter varieties (Table 1). The higher butyric acid production in ensiles of forage varieties may also be due to their higher moisture content at the time of ensiling.

The increase in lactic acid and pH, and decrease in acetic, propionic and butyric acid content with maturity agreed with the values in the literature (Fukumi et al., 1979; Hara et al., 1986) who worked on WCR. This increase in lactic acid and decrease in other undesirable acids with the

Table 8. Means of main effect of variety and stage of maturity on chemical composition (%DM) of whole crop rice silage

Treatments	n	Ash	CP	EE	Oa	Ob	OCW	ADF	ADL	ADIN	OCC	CPOCC	NCWFE
Variety													
Akichikara	8	12.3^{f}	8.2^{e}	2.21^{a}	14.5^{a}	38.0^{f}	52.5^{c}	33.6^{a}	6.4^{a}	1.24^{e}	29.8^{c}	6.4^{e}	21.2^{e}
Fukuhibiki	8	12.1^{f}	8.4^{d}	1.86^{f}	3.7^{f}	45.2^{d}	48.9^{e}	31.9^{c}	5.5^{d}	1.40^{c}	33.9^{b}	6.5^{d}	25.6^{b}
Habataki	8	13.3^{d}	9.1^{a}	1.96^{d}	10.9^{b}	34.9^{g}	45.8^{f}	31.0^{d}	6.1^{b}	1.59^{a}	35.6^{a}	7.2^{a}	26.5^{a}
Hokuriku 168	8	12.7^{e}	8.0^{f}	2.01^{c}	7.1^{c}	44.6^{d}	51.7^{d}	33.4^{a}	5.1^{e}	1.26^{de}	30.3^{c}	6.2^{f}	22.0^{d}
Tamakei 96	8	14.5^{b}	8.6^{c}	1.92^{e}	7.3^{c}	46.9^{c}	54.2^{b}	31.3^{d}	6.5^{a}	1.46^{b}	25.7^{d}	6.7^{c}	17.0^{g}
Yumetoiro	8	15.3^{a}	8.9^{b}	1.76^{g}	4.9^{d}	41.7^{e}	46.1^{f}	30.9^{d}	6.1^{b}	1.45^{b}	33.6^{b}	7.0^{b}	24.9^{c}
Hamasari	8	14.6^{b}	7.3^{g}	2.15^{b}	4.0^{ef}	51.3^{a}	55.2^{a}	32.6^{b}	6.0^{bc}	1.27^{d}	25.6^{d}	5.6^{g}	17.9^{f}
Kusanami	8	14.0^{c}	7.2^{g}	2.13^{b}	4.7^{de}	49.8^{b}	54.5^{b}	33.6^{a}	6.3^{ab}	1.20^{f}	25.8^{d}	5.5^{h}	18.2^{f}
Stage of maturity†													
MS1	16	16.2^{a}	8.8^{a}	1.98^{b}	12.1^{a}	52.2^{a}	64.3^{a}	40.9^{a}	6.2^{a}	1.36^{b}	13.7^{d}	6.9^{a}	4.8^{d}
MS2	16	13.5^{b}	8.2^{b}	2.33^{a}	7.3^{b}	44.7^{b}	51.9^{b}	32.6^{b}	6.1^{a}	1.23^{d}	28.5^{c}	6.3^{b}	19.8^{c}
MS3	16	12.2^{d}	7.7^{c}	1.93^{c}	5.8^{c}	40.0^{c}	45.8^{c}	29.0^{c}	6.0^{a}	1.29^{c}	37.4^{b}	5.9^{c}	29.6^{b}
MS4	16	12.6^{c}	8.2^{b}	1.77^{d}	3.4^{d}	39.3^{d}	42.3^{d}	26.6^{d}	5.7^{b}	1.55^{a}	40.6^{a}	6.3^{b}	32.5^{a}

† MS1, MS2, MS3 and MS4 described in Table 1.

$^{a, b, c, d, e, f, g}$ values with different superscripts in a column within the same subclass differ ($p<0.001$ to 0.05).

increase in maturity may be due to the decrease in moisture content with maturity. This suggests that the DM content of WCR likely to be increased to improve fermentation quality. Wilting is likely to be a good option to increase DM content of WCR before ensiling. However, the results suggest that pH may be increased with the increase in maturity and hence pH may also be increased in wilted silage with the increase in DM content. Therefore, other options such as inoculants (Hunt et al., 1993; Nia and Wittenberg, 1999; Ridla and Uchida, 1999) and enzyme treatment (Adogla-Bessa and Owen, 1995a; 1995b) may also be considered in addition to wilting to improve fermentability of WCR.

The higher ash content of forage varieties may be due to their higher leaf content, which also contains higher ash (Hara et al., 1986) and silica (Yahara et al., 1981) than other botanical fractions. However, it can be seen (Table 8) that the ash content of two of the grain varieties (Tamakei and Yumetoiro) at MS4 was exceptionally high. This high ash content of these varieties is likely to be due to the fact that a portion of silage was rotten during the ensiling process, which might lead to their higher ash content and not due to leaf or stem of these varieties. This is supported by the fact that among grain varieties, only Yumetoiro and Tamakei 96 at MS4 were high in ash. The higher EE content of forage varieties than grain varieties may be that the leaf content of the former was higher than the latter. The lower content of OCW in Yumetoiro and Habataki on the other hand may be due to their higher proportion of head. The lower ADIN content of forage varieties than grain varieties suggest that presumably ADIN is higher in head than in the straw fraction. In contrast, the higher CP in OCC in grain types than forage varieties explains that most of the CP in grain varieties is likely to remain in the head fraction. The ADIN content of WCR was similar to the grass silages but was more than twice as high as baled grass silages (AFRC, 1993). The higher fiber (OCW and ADF), and lower OCC and NCWFE contents of forage varieties may be because of their higher proportion of stem and lower proportion of head than the grain varieties (Table 3 and 4).

The decreased ash content of WCR with the increase in maturity (Table 8) agreed with the data of Fukumi et al. (1979). However, as stated, that part of the crops at MS4 in both Tamakei and Yumetoiro in the present study was spoiled which may also be the reason for their higher ash content. The ash content of samples used in the present study was almost twice as reported (7.9-9.5%) by Hara et al. (1986), but similar or slightly higher than that reported (9.3-14.2%) by Fukumi et al. (1979). The higher ash content of WCR in the present study may be because of the higher proportion (%DM) of leaf blade (15-38 vs. 11-15) and lower proportion of head (7-60 vs 54-61) than those reported by Hara et al. (1986).

The trend of decrease in CP with maturity, similar to that of ash agreed with the data in literature (Yahara et al., 1981; Nakui et al., 1988) and the reasons may be similar that explained for ash. However, unlike ash, grain varieties contained higher CP than forage varieties may be because of the rice seed, which contains higher CP (AFRC, 1993). The CP content of WCR at similar maturity stages agreed with the data of Nakui et al. (1988), but was slightly higher than that reported by Yahara et al. (1981) and slightly lower than that reported by Hara et al. (1986). The highest EE content at MS2 in all varieties agreed with the results of Fukumi et al. (1979) although reason was not evident. In contrast, some workers (Hara et al., 1986; Nakui et al., 1988) reported a consistent decrease in EE with the advance in maturity.

The decreased fiber (OCW, Oa, Ob, ADF), ADL and ADIN contents with the increase in maturity may be due to the increased proportion of head with the increase in maturity. The decreased fiber and lignin contents with maturity were consistent with values in the literature

(Fukumi et al., 1979; Hara et al., 1986) and is likely due to the higher development of grains in WCC unlike many forage where fiber and lignin increased with maturity (Hoffman et al., 1993).

CONCLUSIONS

Yield of both forage and grain varieties were high although some of the grain varieties yielded less than forage varieties. However, the biomass of forage varieties consisted of a higher proportion of straw in contrast to grain varieties. Yield increased with the increase in maturity, similar in pattern to that of head. Although fermentability of WCR was not good, the quality improved with the increase in maturity. This difference in variety in addition to the stages of maturity alters the proportion of botanical fractions significantly and has a large effect on chemical composition. Finally, harvesting around 40 days after flowering (i.e. at MS4) ensures higher yield, better fermentability and improves quality of WCR by reducing ash, lignin, ADF, and by increasing nitrogen-free cell wall extract.

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