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EFFECT OF RESTRICTED FEEDING IN THE FAR-OFF PERIOD ON PERFORMANCE AND METABOLIC STATUS OF DAIRY COWS*

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Abstract

The aim of the study was to investigate experimentally the effects of restricted or *ad libitum* feeding in the far-off period on performance of dairy cows. Two groups of Polish Holstein-Friesian cows having 19 animals in each group were allotted to two planes of nutrition in the far-off period from –56 to –22 days. The ADLIB group was fed *ad libitum* (DMI 12.9 kg) while in the RES group the dry matter intake was restricted by 3 kg DM compared to the average dry matter during the last 7 days in the ADLIB group. Average daily energy intake decreased from 8.90 UFL in the ADLIB to 6.83 UFL in the RES group. In the close-up period and after parturition, the cows of both groups were given the same diet. In restrictively fed cows, there was a tendency to a greater decrease in BCS during both the dry period (P=0.09) and lactation (P=0.07). After parturition milk production, fertility indices and blood concentration of IGF-1, insulin and glucose were not significantly affected by the far-off treatment. In the RES group, lower BHBA 3 days before calving and on day 5 of lactation and lower NEFA on day 28 of lactation were recorded. Also in this group higher levels of glucose 3 days before calving, triiodothyronine (T_3) on days –30 and 5, and thyroxine (T_4) on days -3 and 28 were observed. It is concluded that restricted feeding in the far-off period positively affected blood indicators of lipomobilization during the transition period, but had little effect on performance of lactating cows. In spite of low energy, high-fibre diet offered *ad libitum* in the far-off period resulted in the energy overfeeding compared to the INRA system recommendation.

Key words: dairy cow, energy intake, body condition score, fertility, metabolic profile

Dynamic metabolic and hormonal changes occur in dairy cows in the periparturient period and the skill of leading the cow through this period is the most important for the cow's metabolic status, fertility indices and the profitability of milk produc-

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tion (Mulligan, 2012). Walsh et al. (2008) reported that nutrition and management of dairy cows during the transition period has an enormous capacity to alter the metabolic status and fertility of lactating cows. Despite the appearance of numerous new concepts of cow nutrition during the dry period, the model consisting of two subperiods is still the most frequently used: the far-off period including the first five weeks of the dry period and the 3-week close-up period (Kokkonen, 2005). An important part of the development of new strategies of nutrition management in this period includes research on the controlled energy diet by means of restrictive nutrition or a high-fibre diet in both periods. Dann et al. (2006) claim that cows in the far-off period over-consume dry matter by as much as 60% of their requirements if fed *ad libitum*. Douglas et al. (2006) showed that feeding a diet with a moderate energy concentration (80% of the demand according to the NRC standards) in the far-off period reduces the negative energy balance during lactation and the concentration of non-esterified fatty acids (NEFA) and the β-hydroxybutyric acid (BHBA) in the blood during the first period of lactation. Also in other research, a reduction in the energy intake during the far-off period resulted in an increase in the dry matter intake during lactation and improved the metabolic profile indices (Grummer, 1995; Cameron et al., 1998; Holcomb et al., 2001; Knight, 2001; Urdl et al., 2007). In addition, Holtenius et al. (2003) found that restrictive feeding, as one of methods for limiting energy intake, may beneficially limit the use of the body fat reserves during the first weeks of lactation. Janovick Guretzky et al. (2006) found that low-energy diet in the dry programme may have a positive influence on the fertility indices of high-producing dairy cows. Not all research results pertaining to this period are unambiguous. Kunz et al. (1985) and Agenas et al. (2003) showed that the application of restrictive feeding from week 10 to 6 before parturition did not have any influence on an increase in dry matter intake before and after parturition. Kokkonen (2005) concluded that feeding restricted according to or below the requirements prevented a decrease in feed intake during the last two weeks of pregnancy, and that a large decrease in insulin by high-energy feeding during the close-up period is unnecessary and may disturb adaptation from pregnancy to lactation.

We hypothesized that reduction of dry matter intake during the far-off period could avoid overfeeding and prevent negative energy balance after parturition while improving fertility and lactating cow performance.

The aim of the study was to determine the effect of lowering dry matter intake in the far-off period on the prepartum and postpartum metabolism and performance.

Material and methods

Animals, experimental design

The experiment was conducted with the approval of Local Ethics Committee for Experiments on Animals No. 10 in Poznań (64/2007).

Thirty-eight multiparous high-yielding dairy cows of the Polish Holstein-Friesian breed weighing 660 kg at dry-off were used. On the basis of analogues including body weight (BW), body condition score (BCS) at dry-off, previous lactation

milk yield, and lactation number they were randomly assigned to one of two groups (ADLIB or RES). Average milk performance in the previous lactation was as follows: ADLIB – 10245 kg, RES – 10561 kg of milk. Average number of lactation periods was 1.90 and 1.78 for the ADLIB and RES groups, respectively.

The cows were fed one of two different amounts of the same TMR (0.69 UFL/1 kg DM, 11.4% CP DM) during the far-off period, from 56 to 22 days before expected day of parturition. The ADLIB group was fed *ad libitum* and in the RES group the dry matter intake in the diet was lowered by 3 kg compared to the average daily dry matter in the ADLIB group in the previous 7 days. Average dry matter intake in the far-off period in the ADLIB (12.9 kg) and RES groups (9.9 kg) provided daily 8.90 and 6.83 UFL per cow for the ADLIB and RES groups, respectively.

Table 1. Ingredient and nutrient concentration of the experimental diets

	Far-off diet[1]	Transition diet[2]	Lactation diet[3]
Ingredients (% DM)			
wheat straw	34.5	-	-
soybean meal	4.1	10.0	10.0
alfalfa silage	18.0	11.0	18.0
maize silage	42.1	20.8	20.1
grass silage	-	10.8	-
maize grain silage	-	9.7	7.9
sugar beet pulp silage	-	5.5	6.7
brewer's grain silage	-	8.2	7.0
hay	-	5.2	6.1
barley grain	-	7.1	6.7
triticale grain	-	5.5	7.0
rapeseed meal	-	-	5.0
glycerol	-	1.3	-
fat	-	-	3.0
minerals and vitamins	1.3	4.9	3.6
Nutrient concentration (in 1 kg DM)			
UFL	0.69	0.82	0.91
PDIN (g)	66	97	113
PDIE (g)	70	98	106
CP (%)	11.4	16.4	17.8
NDF (%)	52.7	35.3	28.3
ADF (%)	34.5	20.3	19.6
Ca (g)	7.1	7.4	9.7
P (g)	3.3	3.7	3.6

[1]from 56 to 22 days before calving.
[2]close-up and fresh diet (during close up – anionic salt supplementation – DCAD –3 meq/100g DM).
[3]from 22 to 90 days of lactation.

The research covered the far-off and close-up periods as well as the first 90 days of lactation. The nutritional value of the feed components was calculated on the basis of the analysed content of nutrients using the module PrevAlim 3.23. The diets were balanced according to the French INRA system recommendation (INRATION

3.3 program). Cows were fed a total mixed ration (TMR), which was given to the animals twice a day: 9.00 AM and 2.30 PM, based on silage made of maize, grass, alfalfa and concentrates (soybean meal, rapeseed meal, barley, triticale) with mineral and vitamin supplements. From 21 days before the expected parturition to 21 days of lactation, cows were offered a similar transition total mixed ration *ad libitum* (0.82 UFL/kg DM, CP 164 g/kg DM). In the transition period, from 21 days before the planned parturition, the cows were additionally supplemented with 300 g anionic salts and the DCAD (dietary cation-anion difference) in 1 kg DM was –30 meq. From 22 to 90 days of lactation, the cows in both experimental groups were fed *ad libitum* with the same lactation TMR with the highest nutritive value (0.91 UFL/kg DM, CP 178 g/kg DM). The composition and nutrient concentration of the diets are presented in Table 1. In the far-off period and from 6 days of lactation until the end of the study, the cows were housed in group pens.

Sample collection and analytical method

Weekly forage, concentrate and TMR samples were composite for monthly analysis by wet chemistry for crude protein (CP, method 976.05, AOAC, 2007), neutral detergent fibre (NDF, PN-EN ISO 16472, 2007), acid detergent fibre (ADF, PN-EN ISO 13906, 2009), calcium (Ca, method 968.08, AOAC, 2007) and phosphorus (P, PN ISO 6491, 2000). The body condition scoring (BCS) was performed in accordance with the methodology by Edmonson et al. (1989) during the far-off period (days –56 and –30), on the parturition day and on days 14 and 56 of lactation.

The cows were milked twice a day and individual milk yields were recorded daily. Milk was sampled at weekly intervals from morning and afternoon milkings. Samples were collected into tubes with 2-bromo-2-nitropropane-1,3-diol, next refrigerated and delivered to a commercial laboratory (Milk Testing Laboratory, Polish Federation of Cattle Breeders and Dairy Farmers, Krotoszyn, Poland), and fat, protein, lactose and urea concentrations were analysed. Yield of FCM (4%) was calculated according to Tyrell and Reid (1965) equation.

Reproductive performance, such as days to the first ovulation, first-service conception rate, services per conception and days open was also recorded. The first ovulation was identified by an ultrasound scanner equipped with a 7.5 MHz convex transducer. During the study, the cows' health was monitored and recorded daily. Blood was sampled from the jugular vein 3 hours after morning feeding on days –30 and –3 prepartum and on days 5 and 28 of lactation. Blood samples were collected into tubes with polystyrene separating granules covered with a clot activator, the aliquots were rotated in a centrifuge, and next serum was frozen and stored (–20°C) for later analyses. The concentration of glucose and β-hydroxybutyric acid was analysed colorimetrically by the endpoint method. Measuring absorbance of the incubated samples was determined using a Marcel Media spectrophotometer and a Hellma microcuvette. The concentrations of non-esterified fatty acids (NEFA) were analysed according to the Duncombe's colorimetric method (1964). Serum hormone concentrations were analysed by means of radioimmunoassay (RIA): insulin, insulin-like growth factor-1 (IGF-1), thyroxine (T_3) and triiodothyronine (T_4). Kits of reagents used for the analysis of blood serum are shown in Table 2.

Table 2. Kits of reagents used for the analysis of blood serum indices

Biochemical indices	Test	Producer
Glucose	G7518-400	Pointe Scientific, Michigan, USA
BHBA	H7587-58	
Insulin	PI-12K	Millipore Corporation, Missouri, USA
Thyroxine	OCPG 07-F4	CIS Bioassays, Codolet, France
Triiodothyronine	OCPE07-T3	
IGF-1	DSL-2800	Diagnostic Systems Lab., Webster, USA

Statistical analysis

The results were analysed statistically using the PROC GLM procedure of SAS 9.1 (2004) SAS®/STAT and Duncan's test. The PROC MEANS and PROC UNIVARIATE procedures were also used. To interpret results the following criteria of significance were used: significant ($P \leq 0.05$), tendency to significance ($0.05 < P \leq 0.1$) and not significant ($P > 0.1$).

Results

Cows in the far-off period consumed an average of 12.9 and 9.9 kg DM/day, and energy intake was 8.90 and 6.83 UFL in the ADLIB and RES groups, respectively (Table 3). The effect of dietary treatment in the far-off on BCS is shown in Table 4. In restrictively fed cows, there is a tendency to a greater decrease in BCS both before ($P=0.09$) and after parturition ($P=0.07$). The average condition on the parturition day and on day 56 of lactation in the ADLIB group was higher and the differences were statistically significant ($P=0.05$).

Table 3. Nutrients of far-off diets (per head per day)

	RES	ADLIB
Dry matter intake (kg)	9.9	12.9
Ingredients intake (kg DM)		
wheat straw	3.41	4.45
soybean meal	0.41	0.53
alfalfa silage	1.78	2.32
maize silage	4.17	5.43
minerals and vitamins	0.13	0.17
Nutrients intake		
UFL	6.83	8.90
PDIN (g)	653	851
PDIE (g)	693	903
CP (g)	1129	1471
NDF (g)	5217	6798
ADF (g)	3415	4450
Ca (g)	0.703	0.916
P (g)	0.327	0.426

RES – restricted feeding, ADLIB – *ad libitum* feeding.

Table 4. The effect of dietary treatment in the far-off period on BCS

Group	Days from calving					BCS changes				
	–56	–30	0	+14	+56	–56→–30	–30→0	–56→0	0→14	0→56
RES	3.59	3.51	3.42	3.31	3.25	–0.08	–0.09	–0.17	–0.11	–0.17
ADLIB	3.57	3.55	3.51	3.47	3.39	–0.02	–0.04	–0.06	–0.04	–0.12
SEM	0.03	0.02	0.03	0.04	0.04	0.04	0.03	0.03	0.03	0.04
P-value	0.59	0.46	0.05	0.06	0.05	0.23	0.17	0.09	0.06	0.07

RES – restricted feeding, ADLIB – *ad libitum* feeding, SEM – standard error of the mean.

Table 5. The effect of dietary treatment in the far-off period on reproductive performance

Group	Days to first ovulation	First service conception rate	Services per conception	Days open
RES	27.4	0.33	2.22	125
ADLIB	25.4	0.42	2.08	119
SEM	1.16	0.108	0.295	12.8
P-value	0.43	0.71	0.83	0.82

RES – restricted feeding, ADLIB – *ad libitum* feeding, SEM – standard error of the mean.

Table 6. The effect of dietary treatment in the far-off period on milk performance

Item	Group	1–90 days
Yield (kg)	RES	43.3
	ADLIB	43.3
	SEM	1.85
	P-value	0.99
FCM (4%) (kg)	RES	40.6
	ADLIB	40.4
	SEM	1.72
	P-value	0.97
Fat (%)	RES	3.59
	ADLIB	3.56
	SEM	0.09
	P-value	0.97
Protein (%)	RES	3.20
	ADLIB	3.15
	SEM	0.02
	P-value	0.89
Lactose (%)	RES	4.84
	ADLIB	4.80
	SEM	0.02
	P-value	0.72
Urea (mg/l)	RES	276.7
	ADLIB	278.6
	SEM	7.68
	P-value	0.58

RES – restricted feeding, ADLIB – *ad libitum* feeding, SEM – standard error of the mean.

Differences in the dry matter (energy) intake during the far-off period did not have a significant effect on the majority of fertility indices: days to first ovulation, first service conception rate, services per conception, days open (Table 5).

However, in the ADLIB group, days open was shorter by 6 days. The insemination index was lower by 0.14 and the effectiveness of the first insemination was higher by 0.09. Moreover, the time of the first postpartum ovulation was similar in the RES and ADLIB groups 27 and 25 days after parturition, respectively. In the first 90 days of lactation, average daily milk yield and FCM production and fat, protein, lactose, urea content in milk were not significantly affected by treatment in the far-off period (Table 6).

In the RES group, lower concentrations of β-hydroxybutyric acid (BHBA) on day 3 before parturition and on day 5 of lactation, and lower concentrations of non-esterified fatty acids (NEFA) in the blood serum on day 28 of lactation were observed (Table 7).

Table 7. The effect of dietary treatment in the far-off period on biochemical indices

Item		Prepartum		Postpartum	
		–30 days	–3 days	5 days	28 days
BHBA (mmol/l)	RES	0.498	0.687	0.799	0.690
	ADLIB	0.510	0.922	0.964	0.738
	SEM	0.03	0.04	0.03	0.04
	P-value	0.47	0.01	0.01	0.59
NEFA (mmol/l)	RES	0.146	0.667	1.13	0.290
	ADLIB	0.151	0.730	1.22	0.507
	SEM	0.02	0.06	0.08	0.04
	P-value	0.81	0.45	0.61	0.01
Glucose (mmol/l)	RES	3.31	2.55	1.61	1.59
	ADLIB	3.67	1.15	1.37	1.53
	SEM	0.16	0.31	0.21	0.21
	P-value	0.29	0.02	0.59	0.88
Insulin (μU/ml)	RES	17.9	5.72	2.51	2.52
	ADLIB	23.2	7.27	3.26	2.69
	SEM	1.40	1.03	0.35	0.30
	P-value	0.06	0.44	0.30	0.78
IGF-1 (ng/ml)	RES	348	60.5	34.8	109
	ADLIB	356	44.5	37.5	102
	SEM	14.2	6.04	3.16	9.98
	P-value	0.80	0.19	0.68	0.71
T_3 (ng/ml)	RES	1.58	0.85	0.134	1.177
	ADLIB	1.28	0.935	0.403	1.180
	SEM	0.06	0.06	0.04	0.05
	P-value	0.01	0.51	<0.01	1.0
T_4 (ng/ml)	RES	95.5	35.5	12.6	27.5
	ADLIB	79.3	58.2	8.40	50.2
	SEM	4.29	4.08	1.48	3.74
	P-value	0.06	<0.01	0.15	<0.01

RES – restricted feeding, ADLIB – *ad libitum* feeding, SEM – standard error of the mean.

In this group, a higher concentration of glucose on day 3 before parturition and also higher levels of triiodothyronine (T_3) on day –30 (P=0.01) and of thyroxine (T_4) on day –30 (P=0.06) were found. The cows fed *ad libitum* during the dry period were characterized by a higher concentration of thyroid hormones in blood during lactation (T_3 on day 5 and T_4 on day 30 post parturition). In the ADLIB group, a tendency for higher insulin level on day –30 was recorded. Reducing the dry matter intake of the TMR by 3 kg in the far-off period had no statistically significant effect on IGF-1 levels in the blood.

Discussion

In our study the decrease in dry matter intake from 12.9 to 9.9 kg during the far-off period reduced the daily energy intake from 8.90 to 6.83 UFL, respectively. In spite of the relatively low concentration of energy (0.69 UFL/1 kg) and higher than recommended NDF content in the far-off diets, cows fed *ad libitum* consumed approx. 130% energy of INRA recommendation for the 8th month of pregnancy (6.9 UFL). We suggested that non-lactating cows do not regulate energy intake according to their requirements when low-energy high-fibre diets are offered *ad libitum*.

Surprisingly in our study, the energy overconsumption decreased BCS by 0.06 points in the far-off period, but it was only 0.06 points higher compared to restricted fed cows. The BCS on the parturition day and on day 56 of lactation in the ADLIB group, as compared to restricted feeding, was higher by 0.09 and 0.14, respectively and the differences were statistically significant (P=0.05). In spite of a higher BCS at calving lately recommended by Mulligan (2012), the postcalving loss of BCS in both groups was low and tended to be lower in groups fed *ad libitum* in the far-off period. Douglas et al. (2006) found that restrictive feeding (7.4 kg DM) decreased the BCS by 0.5 units in the far-off period, while the *ad libitum* feeding improved the BCS in this period by 0.14 units. Also, Dann et al. (2005) showed that the deterioration in BCS condition from 3.05 to 2.85 was caused by a restriction of the dry matter intake (DMI) to 8.16 kg. Silva-del-Rio et al. (2010) suggested that higher dry matter intake in the far-off period is associated with less NDF and greater dry matter digestibility. Rabelo et al. (2005) proposed that ruminal digestibility is higher for low-fibre diets, which increases digesta flow and dry matter intake. In our study in both groups, the day of first ovulation was observed early, possibly indicating a positive energy status, which is also confirmed by a slight deterioration of the BCS during lactation. Ferguson et al. (1990) found that a loss of over 0.5 BCS during the dry period, i.e. higher than that presented in this research, may affect the effectiveness of the first insemination treatment. Opsomer et al. (2000) indicated a negative energy balance shortly after parturition as the most important reason for a delay in the occurrence of the first postpartum heat. Hostens et al. (2012), on the other hand, claim that a "normal" cow manifests heat shortly after parturition, which is connected with peripheral concentration of insulin, IGF-1 and glucose. In our study in the group of cows fed *ad*

libitum during the far-off period, better fertility indices were obtained for first service conception rate, insemination index and days open; however, these differences were not confirmed statistically. Due to the limited number of animals per treatment, it is difficult to make a definitive conclusion about the benefits of the ADLIB diets in the dry period to fertility variables. Colazo et al. (2009) showed that animals restrictively fed during the dry period, were characterized by decreased fertility indices and, in particular, lower effectiveness of the first insemination and longer days open.

In the current study milk production and composition in the first 90 days of lactation were not significantly affected by treatment in the far-off period similarly to other results (Dann et al., 2006; Grum et al., 1996). Douglas et al. (2006) reported higher milk production (2 kg/day) during the first 105 days of lactation in the cows fed restrictively during the dry period; however, the differences were not statistically significant. Winkelman et al. (2008) reported no significant effect of restricted feeding (9.4 kg/day) compared to *ad libitum* feeding (13.7 kg/day) in the dry period on milk production during the first month of lactation. In an experiment by Silva-del-Rio et al. (2010), daily postpartum milk yield was 5.2 kg higher for cows fed a medium-energy diet during the entire dry period compared to the traditional management with the dry-off and close-up periods.

In the transition period, cows undergo hormonal changes and this affects the regulation of lipolysis and lipogenesis, which are responsible for an increase in fat reserves during gestation and their subsequent release during lactation (Friggens et al., 2004; Sumner and McNamara, 2007). Restricted feeding in the far-off period positively affected lipid metabolism during the transition period by significantly decreasing BHBA 3 days before and 5 days after calving. In our study no statistically significant differences in the NEFA concentration were observed between the groups during the far-off and close-up periods ($P>0.05$). However, higher NEFA concentrations were found on day 28 of lactation in the group which was fed *ad libitum* during the far-off period ($P=0.01$). These results are consistent with Holcomb et al. (2001), who showed that the NEFA concentrations in blood during lactation are lower in restrictively fed cows in the dry period. Moreover, higher blood NEFA concentration, above 0.7 mmol/l was observed in both groups 3 days before and 5 days after calving. The concentration of NEFA reflects fat mobilization level from adipose tissue; in turn, blood BHBA level shows completeness of fat oxidization in the liver. High blood NEFA concentration (above 0.4 mmol/l) in the last week before calving is associated with increased risk of left displaced abomasum (LeBlanc et al., 2005) and culling over the whole lactation (Duffield et al., 2005). Both the restrictively and *ad libitum* fed groups were characterized by a moderate BHBA concentration in blood and this does not indicate subclinical ketosis, which is diagnosed at BHBA concentrations in blood that are above 1.4 mmol/l (Oetzel et al., 2007).

In our study the tendency for a higher insulin concentration in the blood of cows fed *ad libitum*, observed 30 days before parturition, could be the effect of energy overconsumption. Loor et al. (2008) reported that cows fed *ad libitum* were characterized by a higher concentration of insulin, as compared to the restrictive feeding method in the dry period. Also Holtenius et al. (2003), Dann et al. (2005, 2006), Rabelo et al. (2005) and Douglas et al. (2006) showed higher insulin concentra-

tions in blood from overfed cows prepartum compared with those of controlled or restricted intake prepartum. In this experiment, no influence of the nutrition method in the dry period on the IGF-1 concentration was demonstrated (P>0.05). Vandehaar et al. (1999) showed that IGF-1 concentrations both during the dry period and during lactation were positively correlated with the energy balance and it increased with an increase in the energy and protein intake. This is also confirmed by Remppis et al. (2011), who claim that the IGF-1 concentration decreases in early lactation if a negative energy balance occurs. Dann et al. (2006) observed twice as high the insulin concentration in cows fed a ration with a higher energy concentration (150% of NRC recommendation) in the far-off period. Similarly, other authors reported a decrease in plasma glucose and insulin concentrations as calving approached as a part of adaptation to the mechanism allowing cows to mobilize fats and proteins (Grum et al., 1996; Kokkonen, 2005). Winkelman et al. (2008) demonstrated significant effects of both *ad libitum* and restricted feeding on plasma insulin concentrations that decreased as parturition approached, reaching the lowest level on day 4 of lactation. On day 30 before parturition, a higher concentration of T_3 (P=0.01) and a tendency to a higher concentration of T_4 (P=0.06) were observed in the group of the restrictively fed cows, while during lactation, the group fed *ad libitum* during the dry period was characterized by a higher concentration of thyroid hormones. The concentration of thyroid hormones (T_3 and T_4) is positively correlated with the energy balance (Klimiene et al., 2008; Saleh et al., 2011). These results correspond to the tendency to a lower condition loss during lactation, which was observed in the *ad libitum* group.

The results obtained do not provide an unambiguous answer to the formulated research hypothesis. Restrictive feeding and decreased energy intake during the far-off period only partly improved some biochemical blood indices of the metabolic status without affecting cow performance. We suggested that in far-off *ad libitum* feeding, a high-fibre low-energy diet could result in energy overfeeding compared to the INRA system recommendation.

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