

Table S1. Daily macronutrient intake and total energy intake (Mean \pm SD)

Time	Dietary Indicator	PRO Group (n=10)	PEP Group (n=9)	p-value
Week 1	Protein (g)	113.09 \pm 15.38	115.02 \pm 19.73	0.741
	Fat (g)	107.44 \pm 23.58	101.39 \pm 15.25	0.685
	Carbohydrate (g)	569.01 \pm 125.03	603.36 \pm 121.73	0.468
	Energy intake (kcal)	3653.14 \pm 389.03	3407.71 \pm 627.84	0.447
Week 2	Protein (g)	114.24 \pm 16.64	109.77 \pm 13.43	0.773
	Fat (g)	105.26 \pm 27.14	107.29 \pm 16.25	0.655
	Carbohydrate (g)	590.84 \pm 189.32	601.88 \pm 193.23	0.186
	Energy intake (kcal)	3487.55 \pm 713.85	3601.88 \pm 103.81	0.469
Week 3	Protein (g)	111.59 \pm 17.28	107.10 \pm 38.84	0.552
	Fat (g)	106.59 \pm 27.35	111.61 \pm 14.83	0.338
	Carbohydrate (g)	578.89 \pm 145.03	604.98 \pm 147.61	0.289
	Energy intake (kcal)	3227.15 \pm 697.83	3457.38 \pm 977.79	0.512
Week 4	Protein (g)	114.46 \pm 24.03	109.87 \pm 15.38	0.354
	Fat (g)	105.82 \pm 27.95	114.82 \pm 35.46	0.256
	Carbohydrate (g)	601.07 \pm 211.29	589.29 \pm 117.06	0.345
	Energy intake (kcal)	3579.65 \pm 294.01	3305.17 \pm 909.21	0.624

Table S2. Training Time and Heart Rate During the Training Period (Mean \pm SD)

Time	Monitoring Indicator	PRO Group (n=10)	PEP Group (n=9)	p-value
Week 1	Training Duration (hours)	22.32 \pm 2.31	21.47 \pm 3.46	0.218
	Training Heart Rate (bpm)	151.61 \pm 11.17	147.28 \pm 13.72	0.652
Week 2	Training Duration (hours)	23.21 \pm 2.12	22.88 \pm 3.17	0.436
	Training Heart Rate (bpm)	146.35 \pm 9.69	148.46 \pm 8.36	0.362
Week 3	Training Duration (hours)	20.16 \pm 2.14	21.21 \pm 3.05	0.281
	Training Heart Rate (bpm)	147.38 \pm 6.19	149.16 \pm 5.63	0.461
Week 4	Training Duration (hours)	22.78 \pm 3.55	22.37 \pm 2.62	0.172
	Training Heart Rate (bpm)	148.15 \pm 5.38	147.16 \pm 5.67	0.321

Table S3. Sleep and Blood Pressure Monitoring (Mean \pm SD)

Time	Indicator	PRO Group (n=10)	PEP Group (n=9)	p-value
Week 1	Sleep Duration (hours)	58.64 \pm 4.56	59.52 \pm 6.31	0.358
	Deep Sleep (hours)	59.36 \pm 5.54	57.98 \pm 4.67	0.541
	Systolic Blood Pressure (mmHg)	118.25 \pm 4.13	116.12 \pm 3.69	0.321
	Diastolic Blood Pressure (mmHg)	69.39 \pm 6.25	68.17 \pm 6.21	0.584
	Sleep Heart Rate (bpm)	57.18 \pm 3.15	58.29 \pm 2.86	0.564
Week 2	Sleep Duration (hours)	59.54 \pm 7.26	56.89 \pm 9.14	0.416
	Deep Sleep (hours)	58.36 \pm 7.54	56.38 \pm 6.67	0.711
	Systolic Blood Pressure (mmHg)	117.55 \pm 6.33	118.28 \pm 6.49	0.256
	Diastolic Blood Pressure (mmHg)	67.19 \pm 6.25	69.48 \pm 3.29	0.634
	Sleep Heart Rate (bpm)	59.16 \pm 4.25	59.19 \pm 6.87	0.267
Week 3	Sleep Duration (hours)	58.21 \pm 4.06	57.25 \pm 6.24	0.186
	Deep Sleep (hours)	57.26 \pm 6.51	59.18 \pm 5.34	0.658
	Systolic Blood Pressure (mmHg)	118.31 \pm 8.13	119.28 \pm 9.19	0.656
	Diastolic Blood Pressure (mmHg)	68.26 \pm 5.34	68.48 \pm 5.09	0.341
	Sleep Heart Rate (bpm)	56.66 \pm 3.25	57.19 \pm 3.07	0.726
Week 4	Sleep Duration (hours)	57.38 \pm 3.16	59.19 \pm 5.24	0.614
	Deep Sleep (hours)	59.06 \pm 6.54	58.38 \pm 3.47	0.127
	Systolic Blood Pressure (mmHg)	119.15 \pm 3.13	117.08 \pm 6.09	0.562
	Diastolic Blood Pressure (mmHg)	69.29 \pm 4.21	69.22 \pm 3.19	0.434
	Sleep Heart Rate (bpm)	58.19 \pm 3.25	58.67 \pm 4.87	0.621

Table S4. Intervention period weekly training plan for the cross-country skiers

Week 1		
Date	Morning	Afternoon
Monday, Oct 10th	Traditional Skiing: Warm-up 20 min / Large laps for men: 20 laps x 3 / Cool-down 30 min	"Integrated Strength: Jog 20 min, Gymnastics 10 min / Circuit strength training / Six exercises / 60 min. End activity: Stretching and relaxation 30 min."
Tuesday, Oct 11th	Freestyle Skiing: Warm-up 15 min / Technical sliding: 80 min / Cool-down 30 min	Aerobic Endurance: Warm-up 10 min / 20km / Cool-down 30 min
Wednesday, Oct 12th	Traditional Skiing: Warm-up 15 min / Timed small laps: 60 laps / Cool-down 30 min	General Integrated Training: Jog 30 min, Gymnastics 10 min / (Agility, Balance, Imitation) 60 min / Stretching and relaxation 30 min
Thursday, Oct 13th	Traditional Skiing: Warm-up 20 min / Large laps: 20 laps x 3 / Cool-down 30 min	Specific Strength Training: Jog 20 min, Gymnastics 10 min / Specific lower limb strength 60 min / End activity 30 min
Friday, Oct 14th	Freestyle Skiing: Warm-up 15 min / Technical sliding: 80 min / Cool-down 30 min	Specific Strength Training: Warm-up 10 min / Aerobic pole-assisted imitation running 80 min / Cool-down 30 min
Saturday, Oct 15th	Freestyle Skiing: Warm-up 15 min / Timed small laps: 60 laps / Cool-down 30 min	Rest and Adjustment
Sunday, Oct 16th	Specific Strength Training: Warm-up 10 min / Pole-assisted uphill climb / Flexibility and relaxation activities 30 min	Rest and Adjustment
Week 2		
Date	Morning	Afternoon

Monday, Oct 17	Ski pursuit training: 15 min warm-up / traditional large circle 20 laps + freestyle large circle 20 laps / 30 min cool-down	Preparation: 20 min jog, 10 min gymnastics: Comprehensive strength: Pull-ups for 5 min + Sit-ups for 60 sec + Arm and leg linkage for 60 sec + Left side support for 60 sec + Right side support for 60 sec + Box jumps for 60 sec + Ski machine for 5 min / 5 sets / Intervals of 3 min / Cool-down 30 min
Tuesday, Oct 18	Traditional short-distance skiing: 15 min warm-up / 5 large laps x 5 / 30 min cool-down	Aerobic endurance: 10 min warm-up / 10 km (Requirement: under 4'00" per km) Imitation practice for 30 min / 30 min cool-down
Wednesday, Oct 19	Ski pursuit training: 15 min warm-up / traditional large circle 20 laps + freestyle large circle 20 laps / 30 min cool-down	Rest and adjustment
Thursday, Oct 20	Freestyle short-distance skiing: 15 min warm-up / 5 large laps x 5 / 30 min cool-down	Aerobic endurance: 10 min warm-up / 10 km / 20 min gymnastics / Lower body specific strength training: Resistance band lateral kicks with partners 50m + Imitation uphill running 80m (8 sets) / 30 min cool-down
Friday, Oct 21	Traditional skiing: 15 min warm-up / Aerobic endurance technical skiing 40 laps / 30 min cool-down	Aerobic endurance: 10 min warm-up / 10 km / 20 min gymnastics / Upper body strength (Pull-ups 120-150 / Prone row / Bench press / Barbell press / Leg press) / 30 min cool-down
Saturday, Oct 22	Freestyle skiing: 15 min warm-up / Aerobic endurance technical skiing 40 laps / 30 min cool-down	Rest and adjustment
Sunday, Oct 23	Specific strength and endurance: 10 min warm-up / Pole-assisted imitation running for 90 min / 30 min cool-down	Rest and adjustment

Week 3

Date	Morning	Afternoon
Monday, Oct 24	Ski pursuit training: 15 min warm-up / traditional large circle 25 laps + freestyle large circle 25 laps / 30 min cool-down	Preparation: 20 min jog, 10 min gymnastics: High-intensity interval training with bodyweight (eight exercises) two continuous sets as one group / 4 groups / Relaxation 30 min
Tuesday, Oct 25	Traditional short-distance skiing: 15 min warm-up / 4 large laps x	Aerobic endurance: 10 min warm-up / 15 km (Requirement: between 4'00" and 4'30"

	5 / Sliding down the big slope x 5 / 30 min cool-down	per km) / 30 min cool-down
Wednesday, Oct 26	Freestyle skiing: 15 min warm-up / timed laps small circle: 60 laps / 30 min cool-down	Rest and adjustment
Thursday, Oct 27	Ski pursuit training: 15 min warm-up / traditional large circle 25 laps + freestyle large circle 25 laps / 30 min cool-down	Preparation: 20 min jog, 10 min gymnastics: Specific upper body strength: Pull-ups for 10 min / Barbell bench press / Dumbbell raises / 3 sets / Cool-down 30 min
Friday, Oct 28	Freestyle short-distance skiing: 15 min warm-up / 4 large laps x 5 / Sliding down the big slope x 5 / 30 min cool-down	Specific strength training: 10 min warm-up / Aerobic pole-assisted imitation running for 80 min / 30 min cool-down
Saturday, Oct 29	Traditional skiing: 15 min warm-up / timed laps small circle: 60 laps / 30 min cool-down	Rest and adjustment
Sunday, Oct 30	Preparation: 20 min jog, 10 min gymnastics: Specific lower body strength: Flip tires 30m / Resistance band lateral kicks with partners 60m / Weighted lunges 100m / 5 sets / Cool-down with 30 min jog and 20 min stretching	Rest and adjustment

Week 4

Date	Morning	Afternoon
Monday, Oct 31	Ski pursuit training: 15 min warm-up / traditional large circle 25 laps + freestyle large circle 25 laps / 30 min cool-down	Preparation: 20 min jog, 10 min gymnastics: High-intensity interval training with bodyweight (eight exercises) two continuous sets as one group / 4 groups / Relaxation 30 min
Tuesday, Nov 1	Traditional short-distance skiing: 15 min warm-up / 4 large laps x 5 / Sliding down the big slope x 5 / 30 min cool-down	Aerobic endurance: 10 min warm-up / 15 km (Requirement: between 4'00" and 4'30" per km) / 30 min cool-down
Wednesday, Nov 2	Freestyle skiing: 15 min warm-up / timed laps small circle: 60 laps / 30 min cool-down	Rest and adjustment
Thursday, Nov 3	Ski pursuit training: 15 min warm-up / traditional large circle 25 laps + freestyle large circle 25 laps / 30 min cool-down	Preparation: 20 min jog, 10 min gymnastics: Specific upper body strength: Pull-ups for 10 min / Barbell bench press / Dumbbell raises / 3 sets / Cool-down 30 min

Friday, Nov 4	Freestyle short-distance skiing: 15 min warm-up / 4 large laps x 5 / Sliding down the big slope x 5 / 30 min cool-down	Specific strength training: 10 min warm-up / Aerobic pole-assisted imitation running for 80 min / 30 min cool-down
Saturday, Nov 5	Traditional skiing: 15 min warm-up / timed laps small circle: 60 laps / 30 min cool-down	Rest and adjustment
Sunday, Nov 6	Preparation: 20 min jog, 10 min gymnastics: Specific lower body strength: Flip tires 30m / Resistance band lateral kicks with partners 60m / Weighted lunges 100m / 5 sets / Cool-down with 30 min jog and 20 min stretching	Rest and adjustment

Table S5. Selected athletic performance indicators of cross-country skiers in PEP and PRO groups (Mean \pm SD)

Variable	PRO group (n = 10)		PEP group (n = 9)		Two-way ANOVA P-value (p η^2)		
	Baseline	Post-intervention	Baseline	Post-intervention	Interaction	Time	Intervention
Aerobic capacity							
Blood lactate (mmol/L)					0.284 (0.1)	<0.001 (0.984)	0.094 (0.169)
Resting	2.05 \pm 0.79	1.48 \pm 0.46	2.48 \pm 0.56	1.33 \pm 0.64**			
0 (Immediately) ^a	11.33 \pm 1.91†††	9.68 \pm 2.19†††	12.37 \pm 3.2†††	11.17 \pm 2.66†††			
5 minutes ^a	8.8 \pm 2.48†	7.66 \pm 2.45	10.41 \pm 2.85	8.58 \pm 1.85†			
10 minutes ^a	7.79 \pm 2.31	6.87 \pm 2.91	8.32 \pm 3.11†††	7.27 \pm 1.86†			
Heart rate (bpm)					0.786 (0.047)	<0.001 (0.864)	0.107 (0.162)
Resting	70.5 \pm 8.29	62.8 \pm 3.23**	64.22 \pm 7.97	63.11 \pm 6.9			

0 (Immediately) ^a	195.9 ± 3.99†††	197.5 ± 4.65†††	193.11 ± 3.26†††	196.67 ± 3.2**†††
5 minutes ^a	117.5 ± 10.28†††	117.5 ± 11.98†††	106.56 ± 15.3†††	111.56 ± 14.44†††
10 minutes ^a	103.8 ± 8.61†††	101.2 ± 7.79†††	95.11 ± 13.13††	95.56 ± 12.69†††
Anaerobic capacity				
Blood lactate (mmol/L)				0.002 (0.219) <0.001 (0.707) 0.922 (0.014)
Resting	2.12 ± 0.98	3.44 ± 2.45	2.24 ± 0.86	2.83 ± 1.1
0 (Immediately) ^b	12.47 ± 5.33†††	11.68 ± 3.74†††	10.03 ± 1.93†††	7.31 ± 2.67#†
5 minutes ^b	11.95 ± 3.54	9.87 ± 3.04*	11.99 ± 3.14	11.38 ± 2.02
7 minutes ^b	9.96 ± 2.94	9.39 ± 2.77	10.16 ± 1.55	11.21 ± 1.7
9 minutes ^b	7.84 ± 2.11	7.98 ± 1.55	8.73 ± 2.01	9.47 ± 1.34#

^arepresents after exhaustion;

^brepresents after exercise;

Significant difference within Group (*p < 0.05, **p < 0.01);

Significant difference between group (#p < 0.05);

Significant difference compared to the previous time point (†p < 0.05, ††p < 0.01, †††p < 0.001)

Table S6. Differential metabolites screened according to predetermined criteria

PEP group					PRO group				
Metabolite	FC	FDR	VIP	Trend	Metabolite	FC	FDR	VIP	Trend
23-Norcholic Acid	1.580	0.007	1.559	↑	7-Ketolithocholic Acid Methyl Ester	2.008	0.000	1.466	↓
23-Norcholic Acid Diacetate	1.648	0.006	1.640	↑	Acetoacetic acid	1.537	0.002	1.057	↑
7-Ketolithocholic Acid Methyl Ester	0.368	0.012	1.552	↓	D-Xylose	2.371	0.002	1.785	↑
4-ANDROSTEN-3-ONE-17beta-CARBOXYLIC ACID	0.496	0.028	1.297	↓	2'-Deoxyadenosine	1.542	0.002	1.178	↓
N-(4-Aminobenzoyl)-L-glutamic Acid	1.648	0.032	1.311	↑	Oxalacetic acid	0.439	0.002	2.160	↑
3-Hydroxybutyric acid	0.535	0.018	1.391	↓	3-Methyladipic acid	1.570	0.002	1.281	↓
D-Xylose	1.555	0.027	1.382	↑	Cholic Acid	0.634	0.003	1.294	↓
Oxalacetic acid	1.756	0.010	1.732	↑	Dodecanedioic acid	2.605	0.004	1.405	↓
7-Ketolithocholic Acid	1.546	0.013	1.585	↑	alpha-Hydroxyisobutyric acid	0.643	0.004	1.588	↑
5Z-Dodecenoic acid	0.503	0.018	1.255	↓	Dehydrolithocholic acid	2.060	0.004	1.463	↑
alpha-Hydroxyisobutyric acid	1.573	0.010	1.374	↑	Alpha-Linolenic acid	1.679	0.010	1.406	↓
Hydroxyisocaproic acid	1.509	0.014	1.599	↑	Pyridoxal	1.724	0.012	1.858	↑
3-Hydroxyisovaleric acid	0.742	0.028	1.458	↓	Aspartame	0.674	0.016	1.450	↑
Alpha-Linolenic acid	0.291	0.006	1.855	↓	Myristoleic acid	0.467	0.017	1.464	↓
Aspartame	1.746	0.019	1.475	↑	11Z-Eicosenoic acid	1.629	0.021	1.129	↓
Myristoleic acid	0.349	0.007	1.578	↓	8,11,14-Eicosatrienoic acid	0.470	0.021	1.831	↓
11Z-Eicosenoic acid	0.191	0.005	1.860	↓	Shikimic acid	0.384	0.025	1.738	↑
Lauroylcarnitine	0.492	0.023	1.326	↓	Quinic acid	0.704	0.025	1.671	↓
8,11,14-Eicosatrienoic acid	0.531	0.006	1.716	↓	Palmitelaidic acid	0.354	0.029	1.594	↓

Shikimic acid	2.306	0.027	1.545	↑	Glycylvaline	0.481	0.033	1.813	↑
Quinic acid	0.348	0.005	1.856	↓	(S)C(S)S-S-Methylcysteine sulfoxide	0.476	0.033	1.263	↓
11C,14C-EICOSADIENOIC ACID	0.635	0.032	1.302	↓	trans-Piceid	1.564	0.036	1.731	↑
Adipoylcarnitine	0.656	0.028	1.373	↓	2-Methylvaleric acid	0.715	0.041	1.421	↑
Palmitelaidic acid	0.399	0.010	1.543	↓	11-Dodecenoic acid	0.683	0.042	1.301	↓
10Z-Nonadecenoic acid	0.633	0.028	1.429	↓	10Z-Heptadecenoic acid	0.550	0.048	1.347	↓
Glycylvaline	2.003	0.023	1.558	↑	CIS-11,14,17-EICOSATRIENOIC ACID	0.472	0.049	1.848	↓
Leucyl-Glycine	1.742	0.035	1.441	↑	Myristelaidic acid	0.591	0.049	1.455	↓
2-Methylvaleric acid	1.699	0.016	1.615	↑					
11-Dodecenoic acid	0.475	0.023	1.315	↓					
Undecylenic acid	0.528	0.023	1.289	↓					
10Z-Heptadecenoic acid	0.410	0.008	1.581	↓					
CIS-11,14,17-EICOSATRIENOIC ACID	0.526	0.006	1.749	↓					
O-Adipoylcarnitine	0.714	0.048	1.160	↓					
Myristelaidic acid	0.346	0.007	1.575	↓					

FC = fold change; FDR = false discovery rate; VIP = Variable Importance in Projection; ↑ represents upregulate; ↓ represents downregulate