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Maintaining favorable temperature and humidity in beehives as affected by wintering practices

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ABSTRACT

The study experiments aimed to determine the effect of the spatial position of the bee cluster within the hive, the type of cover and the type of food provided during wintering on the optimal temperatures for bee overwintering. It was always observed that the temperatures inside the hive were close (36.47-32.13°C) compared to those recorded outside the hive (33.80-16.43°C). Similarly, relative humidity (RH) inside the hive was maintained within a range of 46.67% to 53.67%, compared to the external RH of 25.33% to 89.33%. Regarding the effect of the bee location inside the hive, it was found that the center of the bee ball maintained a temperature of 26 to 38°C, while the side of the ball recorded 7 to 33°C, followed by the edge of the hive 17 to 31°C with relative humidity levels of 37% to 52%, 23% to 50%, and 33% to 54%, respectively." (The unit °C for humidity is a critical error). Transparent polyethylene for covering the hive was the best in maintaining hive inside temperature followed by coverage with dark blue sheet compared to lower warming effect by the traditional plant remain cover and the uncovered control, while the lowest RH was recorded in the hive covered with plant material. The presence of honey in the bee food recorded less temperatures variation extent (14.60-33.57°C) with a higher RH (39.33-61%) compared to the hive containing protein paste of 12- 34°C and RH of 32.67-47.33%), while the control hive had a temperature varied from 8.70 to 33.53°C C and RH of 34 to 56.33%.

1-Introduction

Honey, as a natural and valuable product with wide applications in the food, pharmaceutical and cosmetic industries, has long had a special place in the human food basket [1]. However, the sustainable production of this strategic product is strongly influenced by the health and survival of the honey bee (Apis mellifera) colony. One of the most critical stages in beekeeping management is the wintering period, when colony losses can be reported as high as 30-50% in temperate and cold regions [2]. These losses not only directly affect honey production, but also indirectly threaten food security and biodiversity by reducing the population of bees as the most important agricultural pollinator [3].

The survival of a honey bee colony during winter is directly dependent on its ability to maintain a stable and favorable microclimate within the hive [4]. By consuming honey and generating heat through the contraction of flight muscles, the colony maintains the temperature of the winter cluster core at 28–32°C, even when the outside temperature drops below freezing [5]. At the same time, controlling the relative humidity inside the hive is also crucial. Too high humidity (generally above 60–70%) can lead to condensation on internal surfaces, increasing the risk of fungal growth, honey spoilage, and diseases such as chalkbrood. Conversely, too low humidity can cause dehydration of the bees and brood [6].

Beekeeper management practices during winter are therefore a critical determinant of colony success .The choice of hive location (open space, covered, cold storage), the type of insulation, the use of different hive designs (e.g. Langstroth versus top bar), and ventilation management are all management variables that have a significant impact on the dynamics of temperature and humidity within the hive [7, 8]. While the general principles of overwintering are established, quantitative evidence linking specific methods to precise hive microclimates—across the cluster center, margins, and overhead space—remains limited and fragmented. Consequently, the relationship between these internal conditions and subsequent colony survival and spring health is poorly quantified .This study aims to systematically investigate how common overwintering methods affect the hive's internal temperature and humidity. It further seeks to quantify how these microclimatic parameters relate to key colony performance indicators at winter’s end .Clarifying these relationships is essential for developing optimal management protocols to reduce losses and enhance productivity in beekeeping. From a food science and industry perspective, this understanding is a fundamental step toward ensuring the sustainable production of honey and the preservation of vital pollination services.

2- Materials and Methods

2.1. Site Description and Experimental Period

The study was conducted in the experimental apiary of the Plant

Protection Department, College of Agriculture, University of Karbala, located in Al-Hussainiya District, Iraq. The experimental period spanned December 2024 to January 2025, encompassing the core winter months to assess hive microclimate under the most challenging conditions.

2.2. Experimental Hives and Colony Standardization

Forty-five visually healthy colonies of *Apis mellifera* were used in this study. All colonies were housed in standard ten-frame Langstroth hives, each consisting of a single deep brood chamber. To minimize confounding variables, colonies were standardized for strength prior to the experiments. Each selected colony contained a known, healthy queen, approximately six frames covered with bees, and four frames of sealed brood, ensuring comparable population density and metabolic potential across all experimental units.

2.3. Experimental Design and Data Logging

The study comprised four distinct experiments, each arranged in a completely randomized design (CRD). Data loggers (Model: DS1923, Maxim Integrated, Accuracy: ±0.5°C for temperature, ±3% for relative humidity) were used to record temperature (°C) and relative humidity (RH %) at specified intervals. Measurements were taken three times daily at fixed time points: 08:00 (morning), 12:00 (noon), and 16:00 (afternoon) to capture diurnal variations. All data loggers were cross-calibrated before deployment.

2.4. Specific Experimental Treatments

2.4.1. Experiment: Baseline Hive Microclimate

This experiment characterized the fundamental difference between the hive's internal and external microclimate. Nine standardized hives were used. One data logger was placed in the central part of the bee cluster (between brood frames), and a second logger was placed 1.5 m from the hive entrance, shielded from direct sunlight and precipitation, to record ambient conditions. Data were recorded for eight consecutive days (n=9 hives).

2.4.2. Experiment: Spatial Variation within the Hive

To assess the microclimatic gradient from the cluster core to the hive periphery, nine hives were instrumented with three data loggers each:

- Location A (Cluster Center): Placed within the center of the bee cluster on a central brood frame.
- Location B (Cluster Edge): Placed at the periphery of the bee cluster.
- Location C (Hive Periphery): Placed in the top corner of the brood chamber, farthest from the cluster. Data were recorded for ten consecutive days (n=9 hives).

2.4.3. Experiment: Effect of Hive Insulation (Covering)

Eighteen hives were randomly assigned to one of four covering treatments (n=3 replicates per treatment):

1. Transparent Polyethylene: Hives were fully wrapped with a 0.15 mm thick transparent polyethylene sheet.
2. Opaque Polyethylene: Hives were fully wrapped with a 0.15 mm thick blue opaque polyethylene sheet.
3. Plant Residues: Hives were insulated by stacking straw bales around and on top of the hive.

4. Control: Hives were left uncovered, exposed to ambient conditions. A data logger was positioned at the center of the brood nest (bee cluster). Data were recorded for seven consecutive days.

2.4.4. Experiment: Effect of Supplemental Feeding

Nine hives were randomly assigned to one of three feeding regimens (n=3 replicates per treatment):

1. Protein Paste Fed: Colonies were provided *ad libitum* with a commercial protein patty placed directly over the top bars of the brood chamber. The patty composition was: soybean powder (25%), brewer's yeast (20%), honey (30%), pollen (10%), vegetable oil (5%), dried egg whites (5%), molasses (4%), and bee-attracting flavors (1%).
2. Honey Fed: Colonies were provided with a supplemental frame of sealed honey placed adjacent to the brood nest.
3. Control (Unfed): Colonies were left to forage naturally and rely on existing winter stores; no supplemental feed was provided.

A data logger was placed in the center of each hive's bee cluster. Data were recorded for seven consecutive days.

2.5. Data analysis

All data were analyzed using JMP® Pro version 16.0 (SAS Institute Inc., 2012). Data were analyzed performing analysis of variance (ANOVA), and the significance of differences between means was compared using the least significant difference (LSD) at a probability level of 0.05 [9]. The computing software SAS 2010 [10] was used for data analysis.

3-Results and Discussion

3.1. Temporal Stability of the Hive Microclimate

Monitoring over an eight-day winter period demonstrated that honeybee colonies maintained a stable internal environment despite significant external fluctuations. The average internal temperature was consistently regulated within a narrow range of 33.29°C to 36.10°C (overall mean: 35.02°C), in stark contrast to the more variable external ambient temperature (mean range: 20.17°C to 25.47°C). A clear diurnal pattern was observed, with internal temperatures lowest in the morning (mean: 34.77°C) and peaking at noon (mean: 35.61°C). Similarly, internal relative humidity (RH) remained stable (overall mean: 50.07%) compared to external RH (overall mean: 49.08%), with the highest internal RH recorded at noon (mean: 50.42%). Statistical analysis (L.S.D., $P \leq 0.05$) confirmed significant effects of time of day and day-to-day variation on both parameters, with significant interaction effects indicating that diurnal patterns were modulated by external weather conditions (Tables 1 & 2).

Table1. Temperature averages showing the difference between inside and outside the beehive for eight days of wintering

	Inside				Outside			
Time period (Day)	Morning	Noon	Afternoon	Average	Morning	Noon	Afternoon	Average
1	35.40	35.43	35.67	35.50	17.23	23.00	20.30	20.17
2	35.70	36.47	36.13	36.10	22.30	30.26	21.83	24.80
3	35.47	36.27	36.23	35.99	21.10	30.20	24.43	25.24
4	35.33	36.23	35.90	35.82	21.63	30.90	23.90	25.47
5	35.17	35.80	35.93	35.63	20.33	28.80	24.63	24.58
6	34.37	35.73	35.60	35.23	17.70	33.80	24.73	25.41

7	34.57	35.33	35.57	35.16	16.43	28.13	25.63	23.40
8	32.13	33.60	34.13	33.29	18.23	28.33	23.50	23.35
Average	34.77	35.61	35.65		19.371	29.179	23.621	
L.S.D. (P≤0.05)	Days 1.064	time 0.651	Interaction 1.842		days 0.673	time 0.412	Interaction 1.166	

Table2. Levels of relative humidity (%) showing the difference between inside and outside the beehive for eight days of wintering

	Inside humidity				**Outside humidity**			
Time period (Day)	Morning	Noon	Afternoon	Average	Morning	Noon	Afternoon	Average
1	49.67	51.00	51.00	50.56	89.33	57.33	61.00	69.22
2	51.33	50.33	49.00	50.22	62.67	41.00	57.00	53.56
3	51.67	50.33	51.00	51.00	63.00	43.33	51.67	52.67
4	52.33	53.67	47.67	51.22	54.33	32.00	35.67	40.67
5	50.33	48.67	49.67	49.56	51.67	35.33	36.33	41.11
6	48.00	47.00	48.67	47.89	58.00	25.33	40.67	41.33
7	51.00	51.33	51.33	51.22	68.00	40.33	37.67	48.67
8	46.67	51.00	49.00	48.89	58.33	36.33	41.33	45.33
Average	50.12	50.42	49.67		63.17	38.88	45.17	
L.S.D. (P≤0.05)	days 3.821	time 2.340	Interaction 6.618		days 2.046	time 1.253	Interaction 3.544	

3.2. Spatial Variation: The Bee Cluster as a Thermal Core

The location within the hive had a profound and statistically significant (P≤0.05) impact on the microclimate. Data from a ten-day period confirmed that the cluster center functioned as a distinct thermal core, maintaining a stable temperature conducive to brood rearing (overall mean: 33.49°C). In contrast, temperatures at the swarm periphery (overall mean: 21.14°C) and outside the hive (overall mean: 21.19°C) were significantly lower and more variable, showing no significant difference from each other. A parallel trend was observed for RH, with the cluster center maintaining the most stable levels (overall mean: 44.54%), while the swarm side and external environment exhibited greater variability (overall means: 39.58% and 45.66%, respectively) (Tables 3 & 4).

3.3. Efficacy of External Hive Insulation

The type of external hive cover significantly altered the internal microclimate over a seven-day period. Transparent polyethylene was the most effective insulator, maintaining the highest average internal temperature (29.81°C) and a stable RH (51.37%). Opaque plastic sheeting also provided substantial insulation, resulting in an average temperature of 26.72°C and the highest average RH (55.80%). Covering hives with plant residues offered a moderate improvement over the control (average temperature: 23.10°C vs. 21.33°C) but was the least effective among the insulation treatments and resulted in the lowest internal RH (39.61%). Uncovered (control) hives experienced the lowest and most variable temperatures (Tables 5 & 6).

Table 3. The effect of bee colony swarming location on hive temperature for ten days during winter

Time period (Day)	Swarming center			Average	Swarming side			Average	Outside the hive			Average
	Morning	Noon	Afternoon		Morning	Noon	Afternoon		Morning	Noon	Afternoon	
1	36.90	35.90	36.70	36.50	16.00	29.63	33.43	26.36	16.90	28.60	30.30	25.27
2	34.17	34.83	36.73	35.24	17.53	28.70	33.77	26.67	18.93	31.17	29.83	26.64
3	34.40	34.87	38.20	35.82	17.90	29.33	27.53	24.92	19.50	30.27	29.70	26.49
4	32.13	34.17	37.37	34.56	16.00	27.43	28.27	23.90	16.37	27.07	30.67	24.70
5	32.53	32.70	37.03	34.09	15.10	19.97	27.17	20.74	15.10	19.83	27.13	20.69
6	32.63	33.57	36.83	34.34	15.43	19.47	26.60	20.50	16.27	19.67	27.33	21.09
7	33.70	32.63	33.10	33.14	14.13	23.20	22.03	19.79	15.87	22.87	22.40	20.38
8	29.60	30.00	32.80	30.80	9.80	20.43	23.27	17.83	10.87	20.53	24.00	18.47
9	29.10	30.57	33.40	31.02	10.10	20.80	22.87	17.92	9.10	21.80	24.03	18.31
10	26.63	28.53	29.07	28.08	7.03	21.77	21.47	16.76	6.97	21.60	17.20	15.26
متوسط	32.18	32.78	35.12		13.90	24.07	26.64		14.59	24.34	26.26	
L.S.D. (P≤0.05)	days 2.253	time 1.234	Interaction 3.903		days 1.795	time 0.983	Interaction 3.109		days 2.876	time 1.575	Interaction 4.981	

Table 4. The effect of bee colony swarming location on hive temperature for ten days during winter

Time period (Day)	Swarming center			Average	Swarming side			Average	Outside the hive			Average
	Morning	Noon	Afternoon		Morning	Noon	Afternoon		Morning	Noon	Afternoon	
1	45.00	44.00	47.67	45.56	57.00	47.67	36.67	47.11	53.33	50.00	50.67	51.33
2	44.00	45.00	46.67	45.22	49.00	44.33	37.67	43.67	52.33	49.33	50.33	50.67
3	44.33	43.33	52.00	46.56	50.33	46.67	37.00	44.67	51.33	49.00	46.33	48.89
4	43.00	44.67	52.67	46.78	48.67	41.33	37.67	42.56	52.33	49.00	44.67	48.67
5	47.33	44.67	44.67	45.56	48.67	49.33	41.00	46.33	50.67	54.33	48.33	51.11
6	48.33	46.00	45.67	46.67	49.67	48.67	40.67	46.33	50.33	53.33	48.33	50.67
7	48.67	44.33	45.00	46.00	41.33	30.67	27.00	33.00	46.33	38.33	34.33	39.67
8	42.67	41.67	38.33	40.89	37.00	32.33	23.33	30.89	41.67	39.33	34.33	38.44
9	43.00	41.33	38.67	41.00	36.67	33.00	23.67	31.11	42.33	40.33	33.67	38.78
10	43.00	42.67	37.67	41.11	43.67	33.33	25.67	33.03	49.00	42.00	38.00	43.00
Average	44.93	43.77	44.90		46.20	40.73	33.03		48.97	46.50	42.90	
L.S.D. (P≤0.05)	Days 5.147	time 2.819	Interaction 8.915		days 3.800	time 2.081	Interaction 6.582		days 3.714	time 2.034	Interaction 6.433	

Table 5. The effect of bee colony swarming location on hive temperature for 7 days during winter

Time period days	Plant remains			Aver.	Opaque plastic sheet			Aver.	Transparent polyethylene			Aver.	Control			Aver.
	Morn.	Noon	Afternoon		Morn.	Noon	Afternoon		Morn.	Noon	Afternoon		Morn.	Noon	Afternoon	
1	20.03	21.93	29.43	23.80	33.00	38.20	37.33	36.18	32.93	35.37	35.37	34.56	10.23	24.97	27.63	20.94
2	12.97	31.47	24.53	22.99	28.07	29.37	31.43	29.62	35.43	31.03	31.90	32.79	13.13	18.07	29.37	20.19
3	18.97	28.23	24.43	23.88	23.47	31.57	24.40	26.48	27.00	31.03	32.03	30.02	14.03	19.03	22.97	18.68
4	17.00	20.60	26.17	21.26	20.40	23.17	31.17	24.91	23.77	28.40	33.50	28.56	15.50	19.83	31.80	22.38
5	19.43	27.57	28.53	25.18	21.63	25.47	31.90	26.33	21.97	30.93	33.47	28.79	8.70	23.07	25.00	18.92
6	12.87	22.77	31.53	22.39	19.00	26.97	31.93	25.97	18.40	31.50	34.00	27.97	12.20	33.53	31.17	25.63
7	14.13	23.60	31.67	23.13	19.43	27.47	32.73	26.54	19.80	31.77	33.40	28.32	10.80	26.60	30.37	22.59
Aver.	16.49	25.17	28.04		23.57	28.89	31.56		25.61	31.43	33.38		12.09	23.59	28.33	
L.S.D.	days	time	Int.		Days	time	Int.		Days	time	Int.		days	time	Int.	
(P≤0.05)	3.574	2.340	6.191		3.020	1.977	5.230		4.237	2.774	7.388		1.700	1.133	2.944	

Table 6. The effect of bee colony swarming location on hive relative humidity for seven days during winter

Time period days	Plant remains			Aver.	Opaque plastic sheet			Aver.	Transparent polyethylene			Aver.	Control			Aver.
	Morn.	Noon	Aftern.		Morn.	Noon	Aftern.		Morn.	Noon	Aftern		Morn.	Noon	Afterno.	
1	35.33	50.00	36.67	40.67	46.00	48.00	49.00	47.67	46.67	49.67	52.33	49.56	52.67	43.00	34.00	43.22
2	40.00	39.67	36.00	38.56	49.33	51.67	50.00	50.33	45.67	56.67	54.67	52.33	46.00	53.00	37.33	45.44
3	38.33	42.67	37.00	39.33	57.00	60.00	57.33	58.11	51.33	53.00	53.33	52.56	47.67	50.00	51.00	49.56
4	40.33	43.67	37.33	40.44	55.00	62.33	50.33	55.89	52.67	53.33	48.00	51.33	50.67	51.00	40.67	47.44
5	41.67	45.33	38.33	41.78	55.00	55.00	50.67	53.56	54.33	48.33	48.33	50.33	46.00	50.67	47.67	48.11
6	40.00	43.00	35.00	39.33	59.00	59.67	51.67	56.78	53.00	52.33	50.00	51.78	56.33	43.33	36.00	45.22
7	39.67	42.00	37.67	39.78	57.00	55.67	57.00	56.56	53.33	51.33	49.00	51.22	54.67	41.00	35.00	43.56
Aver.	39.33	43.76	36.86		54.05	56.05	52.29		51.00	52.10	50.81		50.57	47.43	40.24	
L.S.D	days	time	Int.		Days	time	Int.		Days	time	Int.		days	time	Int.	
(P≤0.05)	4.902	3.209	8.490		5.024	3.289	8.703		5.737	3.756	9.937		3.430	2.245	5.940	

3.4. Influence of Supplemental Feeding on Microclimate

The provision and type of supplemental feed significantly affected the hive's internal environment over seven days. Hives supplemented with protein paste maintained the highest average temperature (23.02°C), followed by those fed honey (22.45°C), and the control group (21.33°C). Conversely, an inverse relationship was observed with RH: honey-fed hives exhibited the highest RH (50.77%), control hives an intermediate level (45.98%), and protein-paste-fed hives the lowest RH (39.18%). Statistical analysis confirmed significant differences for both temperature and RH based on feed type (Tables 7 & 8).

Table7. The effect of feed type on honeybee activities maintaining hive temperature for ten days during winter

Time period days	Honey			Aver.	Protein paste			Aver.	Control			Aver.
	Morn.	Noon	Aftern.		Morn.	Noon	Aftern.		Morn.	Noon	Aftern.	
1	14.93	24.37	26.57	21.96	19.80	27.83	30.07	25.90	10.23	24.97	27.63	20.94
2	17.00	19.43	29.37	21.93	19.13	22.00	32.83	24.66	13.13	18.07	29.37	20.19
3	18.63	22.17	22.50	21.10	20.20	23.50	24.73	22.81	14.03	19.03	22.97	18.68
4	17.97	21.50	31.57	23.53	20.40	23.70	34.33	26.14	15.50	19.83	31.80	22.38
5	14.60	22.43	25.53	20.86	12.47	25.60	31.17	23.08	8.70	23.07	25.00	18.92
6	15.63	27.07	33.57	25.42	13.53	26.27	32.90	24.23	12.20	33.53	31.17	25.63
7	15.93	24.03	30.03	23.33	12.10	26.90	30.33	23.11	10.80	26.60	30.37	22.59
Aver.	16.39	23.00	28.39		16.80	25.11	30.91		12.09	23.59	28.33	
L.S.D	days	time	Inter.		days	time	Inter.		Days	time	Inter	
($P \leq 0.05$)	1.624	1.063	2.813		4.647	3.042	8.048		1.700	1.113	2.944	

Table8. The effect of feed type on honeybee activities maintaining hive temperature for ten days during winter

Time period days	Honey			Aver.	Protein paste			Aver.	Control			Aver.
	Morn.	Noon	Aftern.		Morn.	Noon	Aftern.		Morn.	Noon	Aftern.	
1	56.00	53.67	39.33	49.67	34.33	40.00	33.67	36.00	52.67	43.00	34.00	43.22
2	54.00	55.00	46.00	51.67	36.33	43.33	36.00	38.56	46.00	53.00	37.33	45.44
3	52.00	54.67	52.33	53.00	37.00	39.67	42.00	39.56	47.67	50.00	51.00	49.56
4	49.33	55.00	45.00	49.78	36.67	42.00	37.67	38.78	50.67	51.00	40.67	47.44
5	52.33	61.00	50.00	54.44	39.33	44.67	35.67	39.89	46.00	50.67	47.67	48.11
6	58.67	50.00	40.00	49.56	46.67	38.67	32.67	39.33	56.33	43.33	36.00	45.22
7	52.33	46.00	43.33	47.22	47.33	41.67	35.67	41.56	54.67	41.00	35.00	43.56
Aver.	53.52	53.62	45.14		39.67	41.67	36.19		50.57	47.43	40.24	
L.S.D	days	time	Inter.		days	time	Inter.		Days	time	Inter.	
($P \leq 0.05$)	4.893	3.203	8.475		5.678	3.717	9.835		3.430	2.245	5.940	

4. Discussion

4.1. Interpretation of Key Findings

The results quantitatively demonstrate the honeybee colony's remarkable homeostatic capacity, maintaining a stable core microclimate against external volatility. The maintenance of internal temperatures, particularly the noon peak (~35.6°C), aligns closely with the optimal 34-35°C range required for brood development [11], primarily achieved through collective metabolic heat production [3, 13]. The significant thermal gradient from the cluster center to the hive periphery underscores the colony's super organismal strategy, concentrating thermoregulatory effort in the brood nest while creating an insulating buffer to conserve energy [2, 19].

The superior performance of transparent polyethylene as insulation can be attributed to the greenhouse effect, which passively augments the colony's own thermogenesis. However, the concurrently high RH under synthetic covers highlights a critical trade-off, emphasizing the necessity of adequate ventilation to prevent detrimental condensation [4, 15, 19]. The lower humidity associated with plant residues, while less thermally efficient, may offer an advantage in humid climates by facilitating moisture dissipation.

The differential effects of supplemental feeding underscore that nutritional support extends beyond starvation prevention. The higher temperatures in fed colonies likely result from increased metabolic activity from food processing [3, 21]. The distinct humidity profiles—higher in honey-fed and lower in protein-paste-fed hives—suggest that the feed's physical and chemical properties directly influence the colony's water economy and its regulation of the hive's humidity balance [6, 20, 21].

4.2. Practical Implications and Recommendations

This study provides evidence-based guidance for overwintering management. A synergistic approach combining strategic hive placement, selective insulation, and appropriate feeding is recommended. For optimal thermal stability, transparent polyethylene covers are highly effective, but must be paired with ventilation management. In regions with high ambient humidity, the moisture-wicking property of plant residues may be beneficial despite lower insulation value. Beekeepers should consider not only the caloric value of winter feed but also its type; protein supplements may support thermogenesis while helping to maintain a lower humidity environment, whereas honey may increase moisture levels.

4.3. Limitations and Future Research

This study was conducted over specific short-term periods in winter. Long-term monitoring spanning entire seasons would provide a more comprehensive understanding of microclimatic dynamics and their ultimate impact on spring colony strength and survival rates. Furthermore, future research should directly correlate the quantified microclimatic parameters (e.g., specific temperature/humidity thresholds in the cluster) with concrete physiological indicators of bee health (e.g., hemolymph protein levels, vitellogenin titers) and colony performance metrics (e.g., brood area in spring, honey yield). Investigating the interactive effects of combined management factors (e.g., insulation type paired with specific feed types) would also yield valuable insights for developing integrated overwintering protocols.

5- Conclusion

The overwintering success of *Apis mellifera* colonies is fundamentally linked to the stability of the hive's internal microclimate. This study demonstrates that beekeeping practices are not merely supportive but are critical factors in this process. Key conclusions are:

1. **Bee Cluster Dynamics:** The colony maintains a precise thermal core (32-36°C) around the brood nest, with a significant temperature and humidity gradient extending to the hive periphery.

2. **Insulation Efficacy:** External hive covers are crucial for reducing heat loss. Transparent polyethylene provided the most effective thermal stabilization, while plant residues, though less effective, offered the benefit of reduced internal humidity.

3. **Nutritional Support:** Supplemental feeding, particularly with protein paste, enhances the colony's ability to generate metabolic heat, thereby maintaining higher internal temperatures. The type of feed also directly influences internal humidity levels.

Therefore, for successful wintering, it is recommended to employ a holistic management strategy that includes providing high-quality supplemental feed (both carbohydrates and proteins) and using effective hive insulation, such as transparent polyethylene, while ensuring adequate ventilation to manage humidity. This integrated approach mitigates the energetic demands on the colony, promoting greater survival and vigor entering the spring season.

6- References

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