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HEAT STRESS AND MILK PRODUCTION: MEANS OF ALLEVIATION

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SUMMARY

Milk production of Holstein cows transferred to tropical and sub-tropical regions do not exceed 12 to 15 kg/day which is far below their expected level. The estimated temperature-Humidity Index (THI) for good production performance of Holstein cattle is within the range of 35 to 72. In Egypt, THI is above 72 for four to six months in summer and this, in addition to poor nutrition, during that season, constitute the major environmental constraints to the success of Holstein cattle in Egypt. The physiological responses of heat-stressed Holstein cattle include ; an increase in water intake, urine output, respiratory and skin vaporization ; a reduction in dry matter intake and energy metabolism ; a lowering in all hormones associated with metabolism ; a disturbance in acid-base balance and an elevation in plasma ADH, prolactin and catecholamines.

Poor nutrition can be removed, thus thermal factors are more critical. The increase in dietary potassium, the administration of recombinant-derived bovine somatotropin or recombinant growth hormone-releasing factor and the enhancement of evaporative cooling through the use of various cooling systems could be utilized to alleviate most of the adverse effects of heat stress on milk yield of Holstein cattle.

Keywords : Holstein cattle, heat stress, milk production, alleviation of heat stress.

INTRODUCTION

High environmental temperature, high humidity, poor nutrition, disease and parasites, and animal management constitute the major environmental factors limiting milk production of temperate-evolved cattle in Egypt. Dairy cattle with a high potential for milk production were transferred to tropical and sub-tropical regions with various degrees of success. In most cases the animals showed continuous decline in milk production year after year, and this continued in their next generations.

In order to analyze the reasons behind this decline in milk production of high-yielding cattle we have first to define the thermoneutral zone for milk production. Then we will try to summarize the physiological changes occurring in dairy cattle when exposed to temperatures above this zone. Finally we will try to introduce the various research views concerned with minimizing the effects of heat stress on high-yielding dairy cattle.

THERMONEUTRAL ZONE

The " comfort zone " for milk production is the optimal zone for maximal milk production, a zone in which the animal is within a normal range of body temperature. It is not the zone of minimal heat production or thermoneutrality as it is often erroneously referred to, since the minimal heat production is above the comfort zone for acclimated animals. The level of wind, radiation and/or humidity can alter this zone. For example above the upper critical temperature (21^{O}C) increased air velocity will raise this zone, and radiation and humidity will lower the critical temperature. These zones also vary with the breed of dairy cattle. The upper critical temperature is 21^{O}C for Holstein cattle, 24 to 27^{O}C in Brown Swiss and Jersey and is 32^{O}C in lactating Brahma.

An index that is most useful at the present time is the Temperature Humidity Index (THI) established by the Missouri Climatic Laboratory. This index only considers the two most important factors, temperature and humidity in relatively high producing Holstein cattle. From a climatic view point, it is generally known that good production performance will be obtained on Holstein cattle if the average THI of the climate is not higher than 72 (approximately 21^{O}C at moderate humidity). It has been estimated that an average THI between 35 and 72 enhances milk yield throughout the year for high-producing Holstein dairy animals. A higher THI may be more torable and biological requirements somewhat lower for native tropical cattle and buffaloes. The lowest daily average THI occurs in the Northern Hemisphere in January and are below an estimated critical level in milk production for Canada and Missouri (Fig.1). Some climatic zones are above 72 THI: in Malaysia for 12 months, in Tabasco, Mexico for seven to eight months, in Egypt for four to six months in Phoenix, Arizona for three to four months and in Missouri for two months. The decline in milk yield per THI unit varies with the stage of lactation (production level) and was reported to be 0.9, 0.43 and 0.48 kg/day/THI for early, mid and late lactation (Johnson, 1986).

CLIMATIC CONDITIONS AND HOLSTEIN PRODUCTIVITY IN EGYPT

(Fig. 2) show monthly variations in air temperature and relative humidity from March 1983 to February 1984 in the Alexandria region. Maximum, minimum as well as average air temperatures and relative humidity reach their highest values during summer months. Average maximum air temperature and relative humidity were 29.1^{O}C and 77.4% during that season (El-Nouty *et al.*, 1988). This means that THI in Alexandria region is above 72 at least for four to six months.

El-Nouty *et al.* (1989) compared the milk yield of Holstein cows located in temperate (18 cows from Missouri, USA) and subtropical (32 cows from Egypt) environments during the winter season. Half of each group was high yielders and the other half was low yielders. Means of daily milk yield were 32.2 and 18.6 kg for Holstein-Missouri and 14.6 and 6.7 kg for Holstein-Egypt (Table 1). This means that Holstein cows born and raised in Egypt produce less than half the amount of milk produced by their counterpart in Missouri. The temperate-evolved animals after prolonged exposure to high ambient temperature and low quality roughages undergo long-term acclimatization in tropical and subtropical countries which cause a potentially high producer to compensate physiologically in such functions as mammary gland development and body size resulting in production far below their known or expected level (Johnson, 1982).

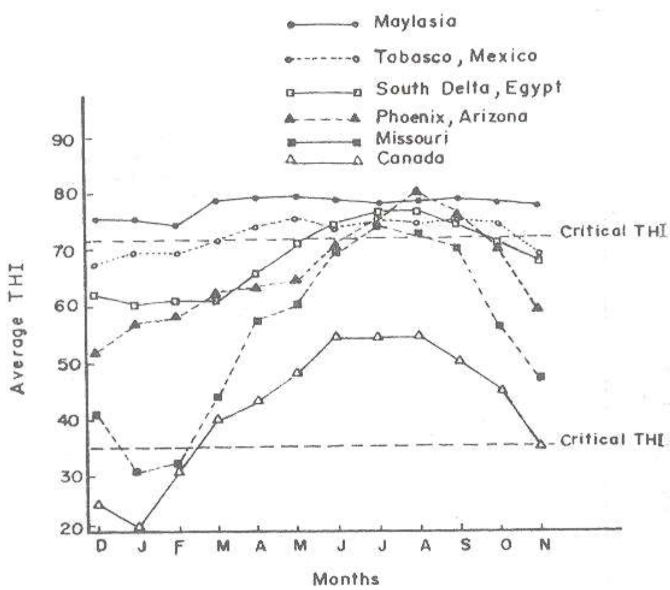

Fig. 1 : Average daily THI for various climate zones in the northern hemisphere.

$THI = T_{db} + 0.36\,T_{dp} + 41.2\,°c$.

THI = Temperature humidity index.

T_{db} = Dry buld temperature (°c).

T_{dp} = Dew point temperture (°c)

Johnson, H.D., 1986.

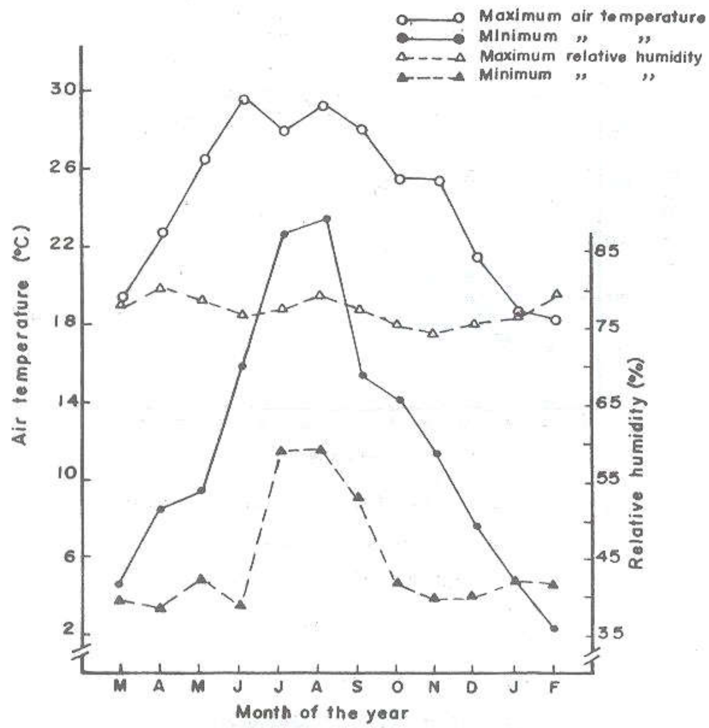

Fig.2 : Monthly variations in air temperature and relative humidity from March, 1983 to February, 1984 in Alexandria region. El_Nouty, F.D., 1988.

Table 1. Means + SE for milk yield and plasma levels of T_4, T_3 cortisol and ADH in high and low yielding Holstien cows located in Missouri (Holstein-M) and in Egypt (Holstein-E).

Parameter	Holstein-M		Holstein-E	
	High	Low	High	Low
Milk production (kg/day)	32.2±0.72 (9)^a	18.6±0.67 (9)^b	14.6±0.47 (16)^c	6.7±0.44 (16)^d
	25.4±1.73^a		10.3±0.81^b	
Plasma T_4 (ng / ml)	36.89±3.49 (9)^a	39.00±3.64 (9)^a	33.82±2.90 (16)^{ab}	25.25±1.88 (16)^c
	37.94±2.46^a		29.67±1.88	
Plasma T_3 (ng / ml)	0.85±0.04 (9)	0.71±0.06 (7)	0.69±0.05 (16)	0.50±0.04 (16)
	0.79±0.04^a		0.60±0.04^b	
Plasma cortisol (ng / ml)	7.63±1.47 (7)	8.18±2.20 (7)	7.51±0.80 (16)	6.86±0.94 (14)
	7.91±1.27^a		7.20±0.60^a	
Plasma ADH (pg / ml)	0.95±0.22 (9)	1.31±0.11 (9)	0.49±0.08 (14)	0.58±0.38 (15)
	1.13±0.13^b		0.04±0.23^b	

a, b, c, d Means in the same row with different superscripts are significantly different (b < 0.05).
Figures in bracktes represent the numbers of observations.
El- Nouty *et al.* (1989).

The increase in milk yield of Holstein cows reared in Missouri as compared with those reared in Egypt was associated with approximately 34 and 28% increase in plasma T_4 and T_3, respectively (El-Nouty *et al.*, 1989), indicating that high milk yield was related to elevated thyroid function.

Habeeb *et al.* (1989) working with Friesian cows in Egypt found that average milk yield decreased by about 30% when they were subjected to heat stress either in climatic chamber (38^oC, 65% RH) or summer heat stress (36^oC).

MODE OF ACTION

The parameters of climate exert both direct and indirect effect on an animal's productivity. Indirectly, it affects the plane of nutrition of animals through the amount of crops and pastures. The direct effect of heat stress is mediated through neuroendocrine system in an attempt to maintain the body temperature within the narrow, optimal range for biological activity. The direct effects of chronic thermal stress on lactating dairy cattle include some modifications or readjustments in the functions of a number of main body -regulating systems resulting in an adverse effect on milk yield and composition:

1. body temperature-regulating system and water balance . Thermal stress causes a rise in core temperature which in turn activate the heat loss mechanism via panting and sweating. This causes dramatic increase in water intake (≈ 30%) and urine output (Table 2). Some of these routes of water loss in addition to other factors may be contributors to changes in acid-base and electrolyte balance.

Table 2.Effcet of TN (1-113 hrs) and heat (1 - 113 hrs) on plasma ADH, aldosterone, watre intake, urine output, serum and urinary sodium and potassium.

Measuremnets	20°C		35°C	
	x	SE	x	SE
ADH (pq/ml)	1.25	.05*[a]	2.11	.07[b]
	(60) **		(64)	
Rectal Temperature (°C)	38.40	.02[a]	39.51	.06[b]
	(64)		(64)	
Hematocrit (%)	35.70	.42[a]	35.70	.53[a]
	(60)		(64)	
Serum Osmolality mOs/kg H_2O	271.58	.58[a]	264.05	.63[b]
	(60)		(64)	
Total Plasma Protein mg /100 ml	8.58	.08[a]	8.48	.06[b]
	(60)		(64)	
Water Intake L / day	50.23	3.35[a]	59.31	1.95[b]
	(12)		(12)	
Urine Output L / day	18.64	1.39[a]	20.89	1.84[b]
	(12)		(11)	
Plasma Aldosterone ng / 100 ml	19.67	.82[a]	16.14	.97[b]
	(60)		(64)	
Plasma Aldosterone ng / 100 ml ***	21.76	1.12[a]	13.99	1.22[b]
	(32)		(32)	
Serum Sodium meq / L	138.07	.39[a]	134.52	.29[b]
	(60)		(64)	
Urinary Sodium meq / L	2.11	.81[a]	6.71	2.42[a]
	(12)		(11)	
Serum Potassium meq / L	4.51	.04[a]	4.23	.03[b]
	(60)		(64)	
Urinary Potassium meq / L	347.61	13.15[a]	296.68	15.18[b]
	(12)		(11)	
Body Weight kg	601.00	19.30	593.00	22.59
	(4)		(4)	

* Values with different superscripts differ, $P < .05$.

** Numbers in parentheses are the number of observations used to determine averages.

*** Average of plasma aldosterone afetr 24 hrs of exposure to TN and heat.

El-Nouty (1979).

2. Feed consumption and energy balance. Increased respiration rate and water intake, which occur as a result of increased environ-mental temperature, lead to the primary concommitant reduction in feed dry matter consumption, and consequently intake of absolute amounts of essential nutrients and metabolizable energy necessary for milk synthesis are decreased.

3. Metabolism of electrolytes and acid-base balance. In severe heat, when body temperature continues to rise, panting is replaced by second phase breathing, which is characterized by a low refrequency and a large tidal volume. Carbon dioxide is eliminated faster than it is produced, pCO_2 is lowered and blood pH rises. Decreased pCO_2 reduces renal tubular acid secretion and exaggerates the compensatory loss of alkali reserve in the urine. This respiratory alkalosis is believed to be involved in reduction of uterine blood flow during thermal stress. The resulting loss of carbon reduces the substrate pool available for salivary buffering of the rumen and is responsible for the lower rumen pH in heat-stressed dairy cows.

Exposure of Holstein cows to heat stress reduces serum and urinary potassium due to its loss via sweating. At the same time serum sodium decreases but owing to the enhanced loss of sodium in urine (Table 2).

4. Endocrine system. Heat stress induces a reduction in some plasma hormones and an elevation in others. Hormones associated with metabolism (e.g. T_4, T_3, GH, Glucocorticoids, aldosterone) tend to be reduced in plasma of heat-stressed cattle. This metabolic adaptation obviously enables heat-stressed cattle to reduce heat production.

Concentrations of prolactin, ADH (Table 2) and catechol-amines in plasma are elevated during thermal stress in dairy cows. ADH infusion was found to reduce milk production in goats (Konar and Thomas, 1970) due to its pressor effect which reduces blood flow to the udder. Catecholamines are well known to oppose the milk let-down effect of oxytocin. The increase in prolactin may be involved in meeting increased water and electrolyte demands of heat-stressed animals.

Effects of chronic thermal stress on lactating dairy cattle are illustrated in Figure 3 by Collier *et al.* (1982). When environmental heat load approximates body temperatures, sensible avenues of heat loss are compromised, leaving only evaporative heat loss as the major route of heat dissipation. This causes a remarkable decreases in roughage intake and rumination. Decreases in roughage intake lead to decreased volatile fatty acid production and alteration in ratio of acetate/ propionate. Rumen pH declines during thermal stress due to decreased buffering of the rumen and/or increases in rumen lactic acid production. The increases in water intake of heat-stressed cattle causes an increase in rumen water content and consequently rumen fluid osmotic pressure declines. Sodium and potassium are reduced in rumen fluid of heat-stressed cattle owing to urinary sodium loss and skin potassium loss as well as decline in plasma aldosterone and increase in plasma prolactin.

MEANS OF ALLEVIATION

Milk production by imported purebreds in tropical and subtropical regions rarely exceeds 12 to 15 kg/day and most usually is less than 10 kg/day. Thus, in addition to climate there are constraints of nutrition, disease and management that can be removed. However environmental heat and humidity will become an increasingly greater constraint as the genetic potential for production is increased and other constraints are removed. The main goal is to prevent the rise in body temperature during hot summer in an attempt to minimize the previously described changes in heat-stressed cattle and this can be partly achieved through several means:

1. Genetic differences, even between individuals of the same breed, are well known to influence the ability to produce milk in climates which are above thermoneutral for several months in the year. Figure 4 illustrating the relative phenotypic differences in the ability of lactating Holstein cows to maintain normal body temperature, eat and produce milk when exposed to environmental heat of 32^{o}C, 60% relative humidity for

three days in climatic laboratory. Fifty-one cows with the ability to produce greater than 25 kg/day at peak of lactation and at thermoneutral (18^{o}C) were exposed to heat (Johnson, 1987). The extremes of this small population (20%) were selected for positive productive adaptability based on less changes in body temperature (< 1.2^{o}C), did not reduce milk yield less than 92% of thermoneutral and did not reduce feed less than 6.5 Mcal/day. The more sensitive group of the population (about 15% of the herd) designated negative productive adaptability increased rectal temperature more than 2.4^{o}C, reduced milk yield to 72% or less and feed intake by more than 12 Mcal/day as compared to thermoneutral. The remainder of the herd were intermediate for these three indices of productive adaptability. This experiment can be easily conducted in the field during hot summer for three days in order to select cows with positive productive adaptability before being imported to the country.

2. As previously mentioned some blood constituents including hormones are elevated or declined in heat-stressed cattle. Physiologi-cally, it is logical to question if restoration of any of these constituents to preheat levels by supplementation or blocking techniques would enhance milk yield under heat. Two approaches are proved to be valid now:

(a) It is now known that increasing potassium in the diet of heat-stressed cattle raises milk production, and the response was greater in unshaded (12%) than shaded cows (6%). Concentrations of plasma prolactin were reduced markedly in both shade and unshaded animals when dietary potassium reached 1.64% (Beede *et al.*, 1981).

(b) In 1937, Asimov and Krouze first demonstrated that injections of crude pituitary extracts containing somatotropin (STH) increased milk production in dairy cows. Because of difficulties encountered in obtaining adequate amounts of exogenous STH, on-farm application was not feasible. Advances in recombinant-DNA technology provided production of large amounts of recombinant-derivded STH (rbSTH). This was accompanied by intense interest in the commercial application of STH. Bauman *et al.* (1985) compared three doses of rbSTH, one dosage of STH, and a control in a long term (188 days) study. They found that rbSTH was effective in improving lactational performance and had greater lactational potency than STH. Cows on rbSTH for 188 days produced 24 to 41% more milk than controls and tended to have higher feed intakes as dose and milk yield increased (Table 3). Hansen *et al.* (1994) studied the effects of bST for two consecutive lactations on lactational performance, health and re-production. They reported linear increase in milk production as bST dose increased during year one but not during year two. Under heat stress administration of highly purified GH (16.8 mg) increased milk production by 3.8 to 12% and fat yield by 9.5 and 12.7% over $heat_1$, and $heat_2$ respectively (Mohamed and Johnson, 1985).

Recently, Binelli *et al.* (1995) compared the effects of recombinant growth hormone-releasing factor bGRF and recombinant bST on somatotropin secretion, mammary function, and body composition of lactating primiparous dairy cows. Cows (118 days of lactation) served as uninfused controls or were infused for 63 days with 12 mg/day of releasing factor or with 29 mg/day of bST. These doses elevated somatotropin in serum to concentrations of similar magnitude. Averaged throughout the infusion period, SCM yields of cows given bGRF (33.3 kg/day) and bST (34.1 kg/day) were greater than those of controls (29.1 kg/day). The bGRF and bST each similarly increased milk components, weight of most organs, mobilization of adipose tissue, accretion of lean tissue in the carcass, and metabolic activity (RNA) of mammary tissue, but neither of them affected cell numbers (DNA) in mammary glands or plasmin in milk.

Table 3. Effect of exogenous somatotropin (mg/day) on yield and composition of milk.

Variable[1]	Control	Pituitary BST	Methionyl BST			
		27.0	13.5	27.0	40.5	SE
Cows, n	6	6	6	6	6	1.8
FCM kg/day[2]	27.9^{a}	32.5^{ab}	34.4^{bc}	38.0^{c}	39.4^{c}	.1
Milk fat, %	3.6	3.3	3.8	3.6	3.6	.1
Milk protein,%	3.4	3.4	3.4	3.4	3.4	.1
Milk lactose,%	4.8	4.8	4.9	4.8	4.9	.1

a, b, c Means in the same row with different superscripts differ ($p < .05$).

[1] Treatment period was 188 days commencing at 84 ± 10 days postpartum. Response data (weekly means) were adjusted by covariance analysis using each individual cow's response during the excipient period.

[2] FCM = 3.5% Fat-corrected milk.

Bauman *et al.* (1985).

3. The maintenance of high level of milk production from the temperate-evolved Holstein cows may require engineering or physio-logical means or both to enhance dissipation of animal heat. Heat loss can be increased by reducing radiant heat load, by increasing convective heat loss, or by increasing evaporative heat loss by wetting the animal's surface. El-Nouty *et al.* (1990) working on quality Holstein cows in Saudi Arabia during hot summer ($42^{o}C$, 34% RH) found that spraying the cows with water caused a marked increase in their daily milk yield that averaged 5.7 /day (26.4%)over that of non-sprayed period (Table 4). Blood hemoglobin, T_4 level, T_4/T_3 ratio and glucose concentration were significantly elevated during spray period than in non-spray period. Cooling may directly influence milk secretion from the mammary gland, but its primary effect is to restore feed intake that had been depressed about 10% by heat stress. Flamenbaum *et al.* (1995) working with Holstein cows during summer lactation used a cooling system of fans and sprinklers. They reported that cooling was effective in maintaining normal body temperature, and increasing feed intake (daily DMI was 1.6 kg higher for cooled cows than for uncooled cows). The opposite effect was observed for water intake, which was 10% higher for the uncooled group.

Therefore, water spray of lactating cows during hot period of the day may prevent the heat-induced depression of thyroid activity, GH and animal appetite and may enhance the milk yield of high producing dairy cattle in tropical and subtropical environments.

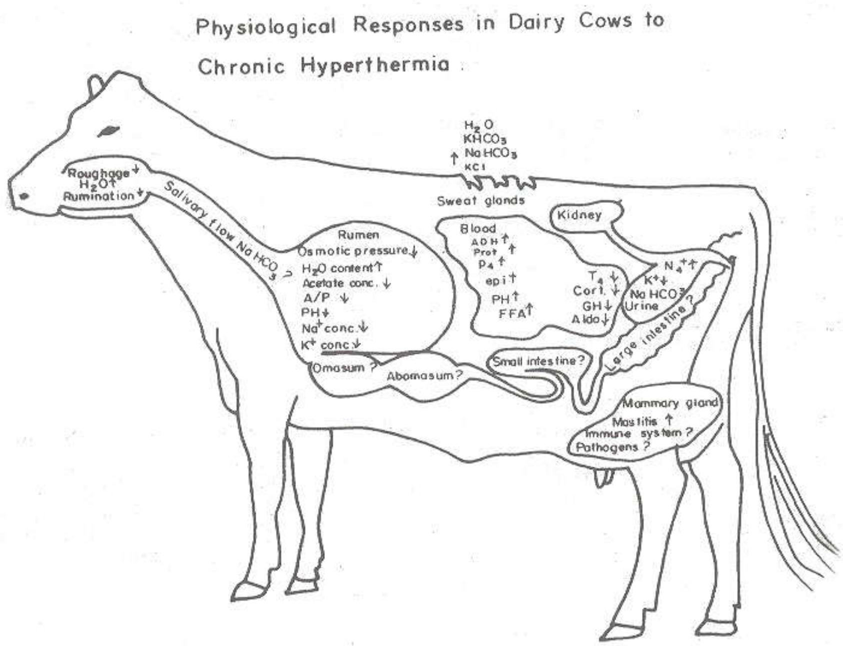

Fig. 3 : Schematic of physiological responses in dairy cows to chronic hyperthermia .

Collier et al., 1987 .

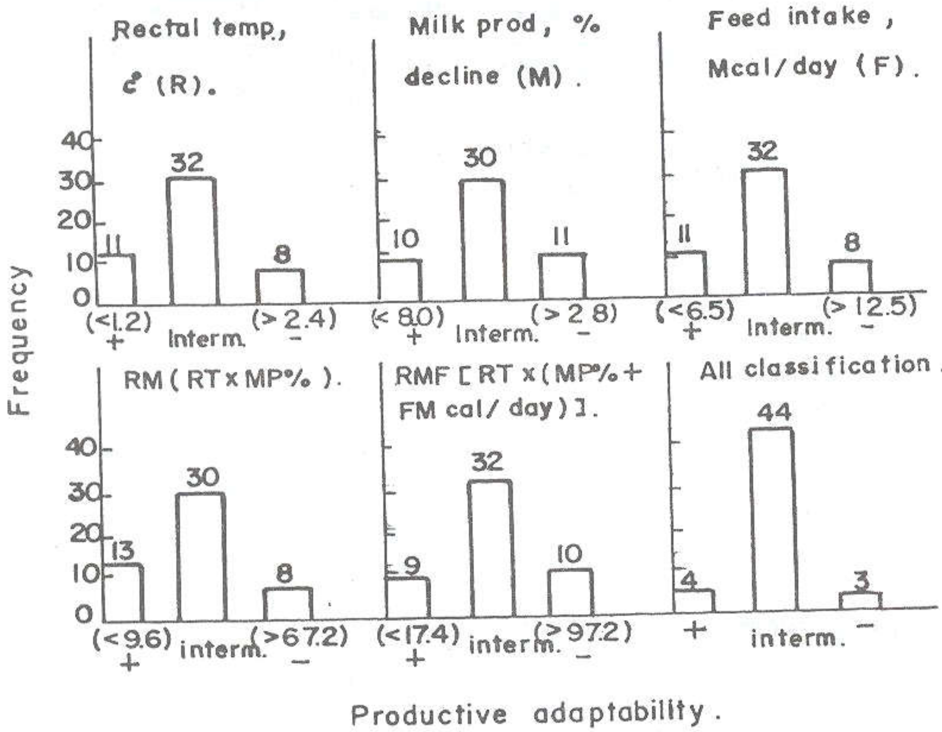

Fig. 4: Frequency distribution for productive adaptability indices.

Johnson, H.D., 1987 .

Table 4. Least-squares means ± SE of milk production and certain blood parameters in lactating Holstein cows during hot-dry summer as affected by water spray.

Parameters	Spray	Non-spray	P*	% in favour of sprayed cows
Milk production (Kg/day)	27.3±0.63[a]	21.6±0.63[b]	0.01	26.4
Hb (g %)	9.8±0.23[a]	9.1±0.23[b]	0.05	7.8
PVC (%)	29.8±0.79	28.6±0.79	ns	4.1
RBC ($X10^6/mm^3$)	5.7±0.16	5.4±0.16	ns	5.4
WBC ($X10^3/mm^3$)	5.3±0.47	5.0±0.47	ns	6.7
TP (g %)	7.3±0.10	7.5±0.10	ns	-1.9
A (g %)	4.2±0.09[b]	4.5±0.09[a]	0.05	- 6.5
G (g %)	3.1±0.12	3.0±0.12	ns	5.0
T_4 (ng/ml)	60.3±3.43[a]	48.5±3.43[b]	0.05	24.5
T_3 (ng/ml)	0.53±0.05	0.58±0.05	ns	- 8.6
$T_4 : T_3$(ratio)	113.8±19.10[a]	83.7±19.10[b]	0.05	36.0
Glucose (mg/100 ml)	34.4±1.58[a]	27.7±1.58[b]	0.01	24.2

a, b Means in the same row bearing different superscripts differ.
*, Probability value.
El-Nouty *et al.* (1990).

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الإجهاد الحرارى و انتاج اللبن : وسائل تقليل التأثير الضار للحرارة العالية

فرحـات الدســوقى النــوتى
قسم الإنتاج الحيوانى ، كلية الزراعة ، جامعة الاسكندرية

انتاج اللبن من أبقار الهولشتين التى استوردت للمناطق الإستوائية وشبه الإستوائية لا يتعدى ١٢ – ١٥ كجم / يوم و هو أقل كثيرا عن انتاجها المتوقع. دليل الحرارة و الرطوبة المناسب لإنتاج اللبن يتراوح بين ٣٥ – ٧٢. وفى مصر يصل دليل الحرارة و الرطوبة الى أكثر من ٧٢ لمدة ٤ – ٦ شهور خلال فصل الصيف كما يتميز هذا الفصل بنقص فى كمية الأعلاف اللازمة لتغذية الأبقار. هذان العاملان يشكلان التحدى البينى لنجاح أبقار الهولشتين فى مصر.

الاستجابات الفسيولوجية لأبقار الهولشتين عند تعرضها للإجهاد الحرارى تشمل زيادة كمية الماء المشروب ، زيادة حجم البول ، زيادة تبخير الماء من الجلد و الجهاز التنفسى ، نقص فى كمية الغذاء المأكول وفى الإنتاج الحرارى ، انخفاض تركيز الهرمونات المرتبطة بالتمثيل الغذائى ، اختلال فى الميزان الحمضى – القاعدى وزيادة تركيز بعض الهرمونات فى الدم مثل الهرمون المانع للتبول وهرمون البرولاكتين و هرمونات نخاع الأدرينال.

ونظرا لأنه يمكن التغلب على مشكلة نقص الأعلاف خلال فصل الصيف ، لذا فإن العوامل البيئية المسببة للإجهاد الحرارى هى الأكثر أهمية. هذا ويمكن عن طريق زيادة مستوى البوتاسيوم فى الأكل أو حقن هرمون نمو الأبقار أو العامل المنبه لإفراز هرمون النمو المصنعان بواسطة الهندسة الوراثية أو تبريد الحيوان بالوسائل الهندسية تقليل معظم التأثير الضار للإجهاد الحرارى على انتاج اللبن.