Adsorption Isotherms and Isosteric Heat (q_{st}) of the flours from three Edible Insects: *Rhynchophorus phoenicis*, *Imbrasia truncata and Imbrasia epimethea*

Aymar Rodrigue FOGANG MBA[a,b*], Germain KANSCI[b], Catherine Loisel[c], **Claude GENOT**[a*]

[a]: INRA, UR 1268 Biopolymères Interactions Assemblages, 44316 Nantes - France
[b]: University of Yaoundé I, Department of Biochemistry, BP 812 Yaoundé – Cameroon
[c]: GEPEA - UMR 6144 (CNRS), ONIRIS, 44322 Nantes, France

Introduction

Entomophagy is practiced in many countries of the world (ref. 1 & 2). Edible insects are sometimes used as ingredients to formulate food products such as cookies and cakes (ref. 3). Prior to that, they undergo treatments such as drying before being transformed into flour (ref. 4). The stability of these flours during processing, packaging and storage depends on their water content and water activity. The larvae of *Rhynchophorus phoenicis*, *Imbrasia truncata* and *Imbrasia epimethea* are eaten in West and Central Africa and sources of lipids and proteins with high potential for human nutrition (ref. 2 & 5).

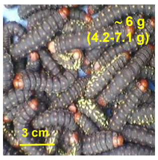
This study evaluated the hydration properties of the flours of *Rhynchophorus phoenicis* larvae *and Imbrasia truncata* and *I. epimethea* caterpillars.

Material & Methods

1. Biological material : Insect larvae

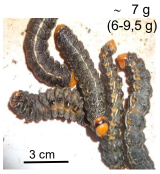
~ 6 g (4-7 g)

Rhynchophorus phoenicis



Imbrasia epimethea

~ 7 g (6-9,5 g)

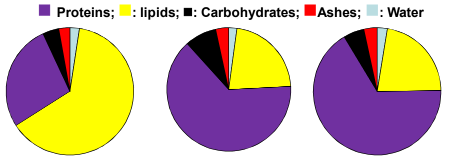


Imbrasia truncata

2. Preparation and composition of insect larvae flours (ref . 2, 5, 6)

Frozen larvae → Freeze dried insect larvae → **Insect flours**

Lyophilisation (72 h, -80°C); Grinding (5 min)



Rhynchophorus phoenicis *Imbrasia truncata* *Imbrasia epimethea*

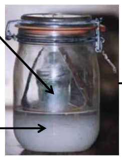
- Lipids are the major component of *Rhynchophorus phoenicis (Rp)* larvae flour. These lipids are rich in unsaturated fatty acids (ref. 2).
- Proteins are major components of *Imbrasia truncata* and *Imbrasia epimethea* larvae flours. These proteins as well as Rp proteins are very rich in indispensable amino acids (ref. 2 & 5).

4. Water activity and adsorption isotherms at 20, 30 and 40° C (ref. 5 & 7)

Saturated salt solution

Salt	Aw 20° C
LiCl	0.11
CH_3COOK	0.23
$MgCl_2$	0.33
$Mg(NO_3)_2$	0.54
NaBr	0.59
$CuCl_2$	0.68
NaCl	0.75
KCl	0.85
BaCl	0.91

Insect flour (~ 200 mg)



20, 30 and 40° C

Insect flours were equilibrated until constant weight

5. Data analysis (ref. 5 & 7)

- Calculation of **equilibrium water content** (Xe) $$X_e = \frac{M_E - M_D}{M_D}$$
- Plot of **adsorption isotherms** $$X_e = f(a_w)$$

A_w = water activity
M_D = Insect flour dry weight
M_E = Insect flour weight after equilibrum

- Modelisation of isotherms with GAB (**Guggenheim-Anderson-de Boer**) model

$$M = \frac{M_0 . C . K . a_w}{[(1 - K . a_w)(1 - K . a_w + C . K . a_w)]}$$

Mo = monolayer moisture content (g/100g dw)
C, K = adsorption constants related to the energies of interaction between the first and the further sorbed water molecules at the individual sorption sites.
R = Universal gas constant (8.314 J.mol^{-1}.K^{-1})

- Calculation of **Net Isosteric Heat** (q_{st}, kJ.mol^{-1}.K^{-1}) $$\ln(a_w) = -\left(\frac{q_{st}}{R}\right)\frac{1}{T} + K$$

Conclusions

- Water content of the freeze dried insect flours (<3 g/100 g) was low enough to limit risks of microbiological or enzymatic alterations when stored at 20, 30 or 40 ° C
- A water content between 2.8 and 5.6 g/100g (Mo) depending on studied insect is required to ensure their maximum stability.
- The adsorption isotherms of the insect flours fitted the GAB model at all temperatures.
- At low moisture content, water binding energies of Rp and Imbrasia flours differed, which can be linked to their respective lipid and protein contents.

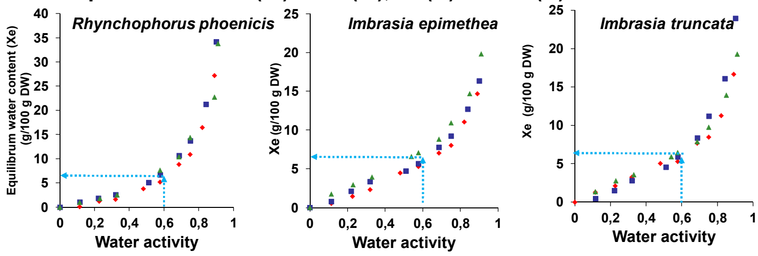
Results & Discussion

1. Water content (WC) and water activity (Aw)of the flours

	WC (g/100 g DW)	Aw 20 °C	Aw 30 °C	Aw 40 °C
Rhynchophorus phoenicis	2,4 ± 0,2 A	0.263	0.295	0.265
I. truncata	2,1 ± 0,3 A	0.159	0.168	0.176
I. epimethea	2,6 ± 0,3 A	0.245	0.232	0.246

The freeze dried insect flours contained less than 3 g water/100 g dry weight (dw) and exhibited low water activity (< 0,3) which should ensure they microbial stability unless further rehydration. As 0.2 <Aw<0.3 is considered to ensure also enzymatical and chemical stability, the *I. truncata* flour could only be subject to oxidative degradation during storage.

2. Adsorption isotherms (AI) at 20 (▲), 30 (■) and 40 (●)° C



Equilibrium water content decreased from 20 to 40° C as expected.
At Aw = 0.6 → Maximum water content for microbiological stability of insect larvae flours

3. Water content for microbiological stability (Aw < 0,6) and GAB mono-molecular moisture content (Mo) of insect larvae flours

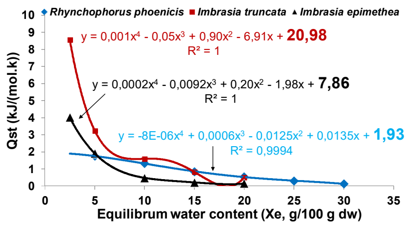
	T (°C)	WC (aw=0.6)	Results of GAB model: Mo (g/100 g dw)	C	K	RStD (%)	R^2
Rhynchophorus phoenicis	20°C	7.9	5.6	1.2	0.9	4.5	0.999
	30°C	7.5	4.5	1.6	1	5.5	0.999
	40°C	5.8	3.3	2.2	1	8.8	0.998
Imbrasia truncata	20°C	7.3	3.8	5.6	0.9	1.8	0.999
	30°C	6.1	3.7	3.2	0.9	5.5	0.999
	40°C	5.6	3.5	2.6	0.9	9.7	0.995
Imbrasia epimethea	20°C	6.7	3.2	9	0.9	6.7	0.996
	30°C	6.4	3.6	2.3	1	5.9	0.999
	40°C	6.1	2.8	8.1	0.9	5.7	0.995

At 20 and 30° C, adsorption isotherms of *R. phoenicis* larvae flours were of type III: easy adsorption of water in monolayer (1<C<2 ; ref 8).
At 40° C, type II behaviour (C>2), corresponding to multimolecular adsorption of water was noticed.

At 20, 30 and 40° C, adsorption isotherms of *I. truncata* and *I. epimethea* were of type II. Type II isotherms were already observed for *Tenebrio molitor* larvae flours (ref. 8), *Acheta domesticus* and *Hermetia illucens* flours (ref. 9).

- ✓ The isotherms allowed excellent adjustment to GAB model.
- ✓ Mo is considered as the optimal water content for preservation of foods. Thus, for obtaining a maximum shelf-life of the insect flours water contents between 2,8 and 5.6 g/100 g dw would be required.
- ✓ Mo of *Rhynchophorus phoenicis* and *Imbrasia l*arvae flours are in agreement with Mo at 30° C of *Tenebrio molitor* larvae flour : 5 g/100 g dw (ref. 9) and *Acheta domesticus* larvae flour : 3,6 g/100 g dw (ref. 10)

4. Net isosteric heat of water sorption by the insect flours (20 - 40° C)



For the 3 insect flours, the results show higher water binding energy at low WC, characteristic of monolayer sorption.

For Rp flour, q_{st} decreased regularly from WC of 5 to 30 g/100 g dw which is characteristic of only monolayer sorption.
For Xe = 0, maximum q_{st} = 21.0 kJ.mol^{-1}.K^{-1}

For *I. truncata* and *I. epimethea* flours, at WC < 7 g/100 g monolayer sorption occurred. At 7<WC<15 g/100 g dw, adsorption continued on less active sites with lower water binding energies. At WC ≥ 15 g/100 g dw q_{st} is close from heat of vaporization of water. In these conditions, microbial, enzymatic and chemical alterations may occur.
Maximum q_{st} *I. epimethea* flour = 7.9 kJ.mol^{-1}.K^{-1} ; Maximum q_{st} *R. phoenicis* flour =1.9 kJ.mol^{-1}.K^{-1}.
To be compared to q_{st} black soldier fly larvae *Hermetia illucens* > 60 kJ.mol^{-1}.K^{-1} and that of house cricket *Acheta domesticus* > 90 kJ.mol^{-1}.K^{-1}) (ref. 10)

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*Contact: claude.genot@inra.fr / aymarfogang@yahoo.fr
Institut National de la Recherche Agronomique, UR1268 BIA
BP 71627 – 44316 NANTES –CEDEX 3- France
Tél. 33 (0)2 40 67 50 71 – Télécopie. 333 (0)2 40 67 50 84

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